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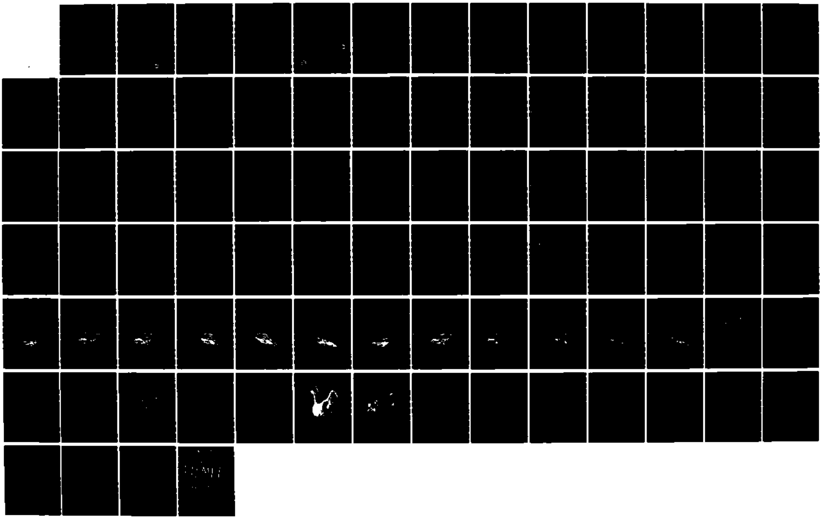

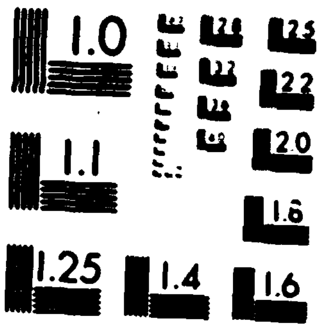

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DEPARTMENT OF OCEANOGRAPHY
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

TECHNICAL REPORT 83-2

GEOLOGICAL AND GEOCHEMICAL ANALYSIS OF SEABED STABILITY AT THE NORFOLK OCEAN DISPOSAL SITE
PART I: GEOLOGICAL ANALYSIS

By

George F. Oertel, Principal Investigator

Final Report
For the period ending September 30, 1982

Prepared for the
Department of the Army
Norfolk District, Corps of Engineers
803 Front Street
Norfolk, Virginia

Under
Contract DACW65-81-C-0051
Work Orders: 0007 and 0008

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General findings of this survey indicate that NDS does not have a spatially and temporarily homogeneous seabed w/respect to stability. The surfaces of pinnacles on ridges may be unstable during the most quiescent summer periods. Fine grained material winnowed from these areas apparently migrates down slope and accumulates in the relatively deep and shielded areas between ridges. Therefore, as winnowed areas, ridges and pinnacles tend to become coarser and deep areas tend to become finer.

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Under
Contract DACW65-81-C-0051
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GEOLOGICAL AND GEOCHEMICAL ANALYSIS OF SEABED STABILITY AT THE NORFOLK OCEAN DISPOSAL SITE
PART I: GEOLOGICAL ANALYSIS

By

George F. Oertel*

INTRODUCTION

The stability of the seabed at the Norfolk Ocean Disposal Site (NODS) affects the fate of materials dumped in that location (figure 1). Insufficient knowledge of seabed stability at the site has prompted a series of analyses of the seabed in an attempt to characterize its present stability. The Norfolk District Corps of Engineers contracted (DACW 65-81-C-0051) with the Old Dominion University Research Foundation to do these studies. Work order numbers 0007 and 0008 (part 2) addressed the problems of seabed conditions and bottom stability at NODS. Details of stability are based upon the evaluation of 40 noncommercial box cores. The distribution of work effort related to work order numbers 0007 and 0008 are shown in table 1. Work order number 0008 is an extension of tasks designed to enhance the evalulation produced by work order 0007; therefore, the reports of these work orders have been combined for the purpose of continuity and clarity.

SAMPLING AND ANALYTICAL PROCEDURES

Large Area Bathymetric Projection

In coordination with the Norfolk District Corps of Engineers and NOAA-NOS, a recent smooth sheet of depth soundings was obtained for the Norfolk disposal site. The smooth sheet was identified as "SMOOTH PLOT, PE-20-2-80" and had over 18,000 data points located between 36°55'N and 37°04'N, anu 75° 26'W and 75°46'W.

Approximately 15,000 data points from the smooth sheet were used to

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construct a three-dimensional, computer generated plot of bathymetry in an 8 nautical mile (nm) square centered around 36°59'N, 75°39'W (figure 2). For the purposes of this investigation, absolute depths were of secondary importance to large scale form analysis. Depths generally ranged from 70 to 80 feet on the east side of the survey area and sloped up to 45 to 55 feet along the western edge of the survey area.

Local Bathymetric Projections

In May and September, 1982, echo sounding surveys were made of a one square mile section of the [illegible] area. The section was centered around 36°59'N and 75°39'W. [illegible] were recorded on a Raytheon DE-719 precision depth recorder [illegible] with a number 7239 Raytheon transducer. Echograms [illegible] transects, each one mile long. Transects followed [illegible] from TDX 27095.50 to 27089.50 about the center position. The chart speed of the PDR was constant at one inch per minute and echogram "fix marks" were made at 30 second intervals to coincide with recorded TD updates. Generally, 16 to 18 updates were obtained per line, depending upon currents, swell, and deviation from the transect line. Three cross-over transects were made diagonally across the survey area to a "closure buoy" located at the initiation point. Cross-over transects were made after the 8th, 16th, and 25th transects were completed to determine the degree of closure and the magnitude of water level change during surveying.

Each data point was adjusted to predicted low water for the survey date, based upon the measured water level fluctuations. From these data, two bathymetric charts (figures 4 and 5) and two sets of six 3-dimensional projections were constructed at a one foot contour interval. The May and September 3-dimensional projections were made from view points (elevation angles) of 30°, 45°, 60°, 120°, 135°, 150° (figures 6-11 and 12-17, respectively).

Box Core Retrieval and Processing

On June 26, 1982, 20 box cores were collected from a one square mile portion of the seabed near the center of NODS. The 20 samples were distributed in a manner to give the most complete coverage of the total area, as

well as the contrasting depths and bathymetric forms (table 2, figure 18). The sea state during the two months prior to sampling was relatively calm. It was expected that these conditions would be reflected in the analyses of the seabed.

A second set of 20 box cores was retrieved from the sampling area on September 9, 1982 (table 3, figure 19). Three major northeast storms passed across the sampling area during the month prior to sampling and it was anticipated that the less stable areas on the bottom might illustrate the influence of these storms.

Upon return to the laboratory, all cores were kept moist and cool, and were processed within 48 hours. Initially, the undisturbed surfaces of all cores were photographed using color film (Appendix 1a and 1b). Cores were then carefully extruded from their stainless steel core liners (10.5 cm x 17.5 cm x 35 cm) into plexiglass trays (2.5 cm x 17.5 cm x 36 cm). Cores were divided into sections (8 cm x 17.5 cm x 1 cm) between the surface and the limits of penetration (figure 20). These sections were analyzed by radiogeochemical techniques. The remaining wafer (2.5 cm x 17.5 cm x length of core) was analyzed by x-ray radiography.

X-ray Radiography and *Analysis*

X-ray radiography of cores was accomplished with a Hewlett-Packard Faxitron Series X-Ray System. Industrial x-ray film was exposed to x-rays through a 2.5 cm thick core wafer. Exposures were at 3 ma with ranges of 60-70 kVp for 4-5 minutes. Film was developed, rinsed, fixed, washed, and dried in the laboratory. The optical density of radiographs was analyzed on a light table. Density contrasts illustrated density changes in the core wafers produced by primary and secondary sedimentary structures, bulk density differences, and grain density differences.

For the purpose of this investigation, the analysis of x-ray radiographs was sectioned vertically. These divisions included the surface unit, from surface to -10 cm, from -10 to -20 cm, and from -20 cm to the limit of core penetration. Each section was characterized as to the primary, secondary, and tertiary occurrence of 8 characteristic sedimentary

structures; ripple foresets, intermediate size (megaripple) foresets, horizontal laminae, tabular textural beds, micro-locomotion bioturbation, macro-locomotion bioturbation, vertical or inclined burrows and dwelling tubes, and structures or textures of unknown origin (table 4).

Grain Size Analysis

Upon completion of x-ray radiography, all core radiographs were briefly scanned to determine the degree of textural homogeneity. If cores appeared to be homogeneous, one representative sample was taken for grain size analysis. Texturally heterogeneous cores were sampled in a manner to best represent the various textural horizons. Samples were labeled to their respective cores and wet-sieved through a 63 micron stainless steel sieve. Material washed through the sieve was analyzed for grain size by gravitational settling; the coarse-grained fraction retained on the sieve was analyzed by standard sieving techniques using half phi intervals. Fine-grained and coarse-grained fractions were combined to establish a cummulative frequency percent curve for each sample. Data from each curve were analyzed for mean, median, mode(s), sorting, skewness, and kurtosis.

Radiogeochemical Analysis

Seven cores were selected for radiogeochemical analyses for thorium isotopes during each sampling period: at stations 3, 7, 13, 14, 15, 16, and 20 in June, 1982, and at stations 3, 6, 9, 13, 14, 15, and 20 in September, 1982. Each core was sectioned in 1 cm intervals in the top 3 cm, at 2 cm intervals from 3 to 9 cm, and at 4 cm intervals for the remaining length of the core. The wet weight of each sample was obtained. The sample was dried in an oven at 100°C ± 10°C to constant weight in order to obtain the water content. A known amount of the dried sediment was ashed at 475°C±25°C for about 24 hours to constant weight. About 5 grams of the ashed sediment was leached with 6N hydrochloric acid at about 90°C for 4 hours in the presence of a known amount of the yield tracer, Th-229. The leachate was

separated from the sediment by filtration through glass fiber filters. The sediment was washed with 6N hydrochloric acid and then discarded. The leachate and the washings were combined, reduced in volume, and then neutralized to pH 7 with concentrated ammonium hydroxide. The precipitates formed were separated from the supernatant liquid by centrifugation and washed with de-ionized water twice. The supernatant liquid and the washings were then discarded. The precipitates were dissolved in 9N hydrochloric acid and then re-precipitated with ammonium hydroxide, washed, and re-dissolved in 9N hydrochloric acid. The acid solution was loaded onto an AG1x8 ion exchange column in the chloride form. The column was eluted with 4-5 column volumes of 9N hydrochloric acid. The eluate was brought to pH exceeding 12 with sodium hydroxide. The precipitates were collected by centrifugation and then washed with de-ionized water three times. The precipitates were dissolved in concentrated hydrochloric acid and the solution was converted to a concentrated nitric acid medium by evaporating the hydrochloric acid away while adding concentrated nitric acid solution. The nitric acid solution was diluted to 8N nitric acid and loaded onto an AG1x8 ion exchange column in the nitrate form. The column was eluted with 8N nitric acid and then 9N hydrochloric acid. The hydrochloric acid fraction was collected and evaporated to near dryness and then converted to 8N nitric acid. The nitric acid solution was evaporated to small drops and transferred to a plating cell. Nitric acid (0.01N) and ammonium chloride were added. Thorium was plated onto a silver disk at 1.5 amps for 2 to 3 hours. The activities of the thorium isotope on the disk were counted for 1 to 3 days and then analyzed by alpha spectrometry. The raw data have to be further processed to yield the activity of Th-228 and Th-232 per gram of the sample on the date of sampling. From the activity ratio of Th-228 to Th-232, one may deduce whether accumulation of sediment is occurring at a given location. From the inventory of Th-228 and Th-232, one may assess the relative rate of sediment accumulation at different locations.

EVALUATION AND DISCUSSION OF SEABED STABILITY

Bathymetric Analysis

The complex bathymetry at the Norfolk Ocean Disposal Site (NODS) may have a significant impact upon seabed stability. Three major scales of

concern must be considered with respect to the stability of this area. Regionally, the site is located just seaward (17 nm) of the entrance to Chesapeake Bay. Outwelling Bay water may occasionally influence the dispersion of material at this site. However, in most cases, the outwelling plume is not believed to have a direct impact on this distant part of the entrance area. Submarine shoals, that could be interpreted as being part of the active ebb data of the Chesapeake Bay, appear to be restricted to within 8 to 12 nautical miles of the inlet throat. Seaward of this area, distal shoals may have been part of a relict ebb delta of a former entrance to an earlier Chesapeake Bay. Bathymetry and channels of the relict Bay entrance system may still be responsible for directing some bottom flowing "water masses." The 60 feet bathymetric contour (NOAA charts 12200 and 12221) adjacent to NODS suggests that the site may be in the vicinity of a relict flood-dominated channel of the former Chesapeake Bay ebb delta (figure 21).

Approximately 50% of the eight nautical mile diameter region illustrated a complex ridge and swale topography above a relatively low relief shelf (figure 22). Three general patterns emerged from the data: 1) smooth, low relief areas, 2) hummocky areas, and 3) ridge and swale areas. The smooth, low relief topography in the northeast part of the region sloped gently seaward from approximately 60 feet to 75 feet. The two smooth, low relief features in the western part of the area were approximately 55 feet deep. In the central portion of NODS, depths of smooth, low relief areas were approximately 70-75 feet. These areas are believed to be stable since they were generally deeper than adjacent regions, and may be beyond the depth of non-storm wave disturbance. Where smooth areas are confined by ridge and hummocky submarine topography, channel-like areas may form. Channels that narrow and "pinch-out" often result in accelerated flow patterns at the distal end of the channel. There are several areas where bottom currents may accelerate because of this process, however, this is primarily controlled by the general circulation over this area of the shelf.

Hummocky areas occurred along the northwestern and southwestern parts of NODS. The shallow areas in these regions occasionally reached depths of 45 feet. At these depths, wave orbital currents in combination with coastal currents may be of sufficient strength to erode or winnow fine-grained

material from the seabed. The result would be a negative skewing of normal grain size populations at hummock crests and a positive skewing in depressions.

The remaining part of the survey area had a pronounced ridge and swale topography that "stepped off" in the seaward direction. These bathymetrically high areas often formed linear mounds or ridges with semi-regular spacings on the order of 0.5 nm between crests. Most of the ridges followed a north to north-northeast trend and were relatively discontinuous. Crests of individual ridges were generally discernible for 2.5 -4 nm, however, several crests appeared to extend for 5.5 nm. It is suspected that the ridge crests are most susceptible to reworking by wave turbulence. Sheltered areas between ridges are more apt to be sites of fine-grained sediment accumulation and greater seabed stability.

In general, the submarine topographic forms in NODS suggested that the seabed on the crests of ridges and hummocks were less stable than swale and deeper, smooth areas.

The one square mile area in the center of NODS is located in a ridge and swale area. Two meandering northeast trending ridges were separated by a swale that opened into a smooth, low relief region. The ridge crests are believed to be within the depth of disturbance by typical waves for an average grain size of 0.125 mm (3 phi). The ridge on the landward side of the survey area trended approximately 30° east of north and the ridge along the seaward side of the survey area trended approximately 20° east of north but terminated in the northern three quarters of the area (figure 23). The relief along the inner ridge crest was 9 feet, with the highest points reaching depths of 57 feet and deepest points achieving depths of 66 feet. The mean depth of the ridge was approximately 62 feet. Three pinnacles separated by two depressions were present on the ridge. Depressions dip toward the south-southeast. Along the outer ridge crest, the relief between three pinnacles and three lows was 5 feet (63 to 68 feet deep).

The two ridges were separated by a funnel-shaped channel that trended 45° to 55° east of north and flared open in the northeast direction. The swale between the ridges had a few "spill-over" type channels that extend into the adjacent ridges. This region of the seabed (68 to 75 feet deep) is

believed to be slightly below the depth of wave disturbance. However, moderate storm waves would most likely generate the shear stress needed to move sediment smaller than 0.15 mm. Most coastal currents flowing over this part of the shelf are expected to have speeds slightly below threshold. However, when bottom flow is from the northeast quadrant, slow moving water may accelerate through the constricted parts of the swale. Occasionally these accelerated flows may cause scour along the margins of the swale and in "spill-over" lobes adjacent to the channel axis. Several deep (possibly scour) pits were observed at the distal or constricted end of the funnel and along the landward side of the seawardmost ridge. Maximum relief for the the entire study area was approximately 18 feet. The steepest gradients were 1:40.

The September 1982 survey illustrated no major variance in geomorphic pattern (figure 24). Minor changes were well within the suspected error limits of surveying and plotting. Thus, within the limits of survey accuracy, the seabed at NODS was stable between May and September, 1982.

Bed Photography

Prior to box core processing, surface features of all cores were catalogued photographically (Appendix 1a and 1b). Descriptions of all core surfaces were noted and compared for the June and September, 1982, samples. Two general trends were recognized: 1) accumulation of finer material and increased worm tube abundance on the smooth, low relief areas and in sheltered regions between ridges, and 2) a general decrease in the amount of fine material with decreasing depth.

Between June and September, three major storms passed over NODS. Each storm was capable of moving fine-grained sediment at depths in excess of 80 feet. Seventy percent of the core surfaces illustrated physical reworking by waves and/or currents during this time. This was indicated by a decrease in the amount of fine-grained material and a complete absence of previously abundant worm tubes on the surfaces of the cores collected from the low relief areas in September. Some samples, generally associated with pinnacles on linear ridges, showed relatively little change over the three month period. Poorly sorted, coarse, iron-stained sands, with numerous

shells and shell fragments, characterized these samples.

At two locations, accumulative surfaces were apparent. Stations 5 and 11 showed an increase in the amount of fine surface material from June to September. Energy associated with the three major northeast storms may be responsible for suspending and transporting fine-grained material into these areas.

Bed surface data illustrated a relatively unstable region for at least 70% of the one mile square area around the center of NODS. This refers to surface material and should not be used as an indicator of bed stability at depths greater than 1 to 2 cm. Several x-ray radiographs indicate the presence of a thin, physically reworked surface layer with a stable subsurface foundation. The transient nature of this surface veneer of sediment is not uncommon at these depths. Therefore, stability of the underlying material will provide a better indication of long-term bed stability.

Textural Analysis

Texturally homogeneous depositional units (as determined by x-ray radiography) were sampled from each core and textural analysis was performed by standard sieve and pipette techniques. Seven major grain size statistics were tabulated for the two sets of cores; percent sand, percent silt, percent clay, mean diameter, sorting, skewness, and kurtosis (tables 5 and 6). It is assumed that processes influencing the stability of the seabed will be reflected in the sediments just below the surface. Four grain size categories were chosen to evaluate seabed stability. The percentages of each sample in these four categories are given in tables 7 and 8.

Seabed stability was estimated based upon the relative percentages of coarse sand, fine sand, and silt and clay. The matrices used to determine samples of greatest stability were based upon the assumption that stable areas generally reflect low energy conditions. These regions would be "receiving" areas for fine-grained sediment. Significant percentages of size classes reflecting stability were estimated to be 60% fine sand, 2% silt and clay, and 4% coarse sand. Based on these criteria, a 3 x 8 stability matrix was constructed from which four categories of "most stable" samples were delineated (table 9). Samples 13, 14, 15, and 20 appeared to be the most stable samples by these criteria.

Using the significant percentages of silt and clay, fine sand, and coarse sand, a second matrix was constructed to estimate the "least stable" areas of the seabed (table 10). The significant percentages used in this approximation were 60% coarse sand, 10% fine sand, and 1.5% silt and clay.

All samples were then categorized based on "most stable" and "least stable" criteria (tables 11 and 12). Categories MS-I, MS-II and LS-I, LS-II are the most significant categories while III and IV primarily represent the completion of the data matrix, with decreasing confidence in the criteria. Six samples could be grouped in the most stable category for both the June and September data sets. Five of the six samples (stations 9, 13, 14, 15, and 20) were from repetitive station locations. These were all located in smooth, low relief areas. In June, only station one fell into the least stable category. It was located on a pinnacle of the inner ridge. In September, four samples (stations 7, 10, 12, and 18) fell into the least stable category by textural criteria. These locations were generally on the margins of the funnel-shaped swale or its "spill-over" channels.

Sorting and skewness were also thought to be useful as parameters for evaluating seabed stability. Since the silt and clay fraction of most samples was less than 5% of the total weight, sorting and skewness were based upon the sand sized particle distributions. Active processes may influence sorting and skewness in several ways. Unstable areas are characterized by poorly sorted, negatively skewed lag deposits. Stable areas of the seabed may be subject to inputs of mobile material from these winnowed, unstable areas. Since the mean grain size of all samples was 2.2 phi (fine sand), and the mobile material is thought to be fine to very fine sand, the degree of sorting may be increased by this addition. Therefore, statistics for extremely stable areas would be well sorted and positively skewed. Tables 13 and 14 are indices of stability based on sorting and skewness. Stations 1, 2, 5, 7, 8, 12, and 18 appeared to be the most unstable; however, only samples 1, 5, and 12 fell in this category on both sampling dates.

The number and position of size modes may also be an indication of relative stability. If a normal distribution is assumed, a deviation from this pattern may result from "winnowing" or "receiving" of fines. Tables 15 and 16 illustrate the primary and secondary modes of all samples. Table 17

is a stability index based on the interpretation of modes as indicators of "winnowing" (unstable) and "receiving" (stable). Using this index, stable and mostly stable areas were located at stations 5, 6, 7, 8, 9, 13, 14, 15, 16, 19, and 20. Unstable and mostly unstable areas were present at locations 1 and 12 in June and at locations 2, 7, 8, 10, 12, and 18 in September. In June, stations 1 and 12 were on pinnacles of the inner and outer ridge, respectively. In September, only samples 2 and 12 were located on pinnacles; samples 7, 8, 10, and 18 were located along "spill-over" channels and at the distal end of the "funnel" channel.

X-ray Radiography

Sedimentary structures were analyzed by x-ray radiography and categorized into four possible classes of primary sedimentary structures and four possible classes of biogenic structures (Appendices II and III). The eight classes of sedimentary structures may be used as indicators of bed stability if it is assumed that physical structures are produced by physical processes such as waves and currents (unstable bed) and biogenic structures are produced by biological processes able to modify physical structures (stable bed). Table 18 is a hierarchy of sedimentary structures. Foreset bedding represents structures of an unstable seabed exposed to higher energy conditions while micro-locomotion bioturbation represents structures of a stable seabed under lower energy conditions where small organisms are able to slowly migrate through the sediment. Tables 19 and 20 illustrate the application of the structurally derived stability index to the NODS samples.

X-ray radiographs were divided into four sections from the surface to a composite of material greater than 20 cm below the surface. Primary, secondary, and tertiary criteria were determined for each of the four zones. For the June data set, stable surfaces occurred at 10 locations (5, 6, 7, 9, 13, 14, 15, 16, 18, and 20). At depths greater than 10 cm below the seabed, stable sediments were suggested for 9 of the 10 stable surface stations, as well as stations 3, 8, and 19. These samples were located in the smooth, low relief areas and on the floors of "spill-over" channels. Unstable surfaces from the June data set characterized stations 3, 4, 8, and 19. These stations were located along the crests or margins of ridges. At depths greater than 10 cm below the seabed, stable sediments were suggested at locations 1, 2, 4, and 17. These four stations were located on pinnacles of the inner ridges.

In September, stable areas of the seabed surface were located at stations 3, 6, 13, 14, 15, and 20. At depths greater than 10 cm below the surface, stable regions were indicated at stations 3, 6, 9, 13, 14, 15, 19, and 20. These stations were all in the deep, low relief portion of the study area or along its western margin. Unstable surfaces were located at stations 4, 7, 12, and 19. Station 4 was on a pinnacle of the western ridge. Structures from the other pinnacles were indistinguishable. At depths greater than 10 cm below the seabed, possible unstable areas were indicated at stations 1, 2, 3, 4, 5, 7, 11, 12, and 16. These locations form an arc from the western ridge around the closed end of the funnel-shaped swale.

COMPOSITE ANALYSIS OF SEABED STABILITY PARAMETERS

The utilization of five different sedimentary parameters as measures of bed stability proved to be very useful. The surfaces of all cores were analyzed using x-ray radiography and photography. These analyses were most informative in recognizing the short term stability of the one nautical mile square area about the center of NODS between June and September, 1982.

In general, worm tubes and surface accumulations of fine-grained material were good indicators of stable seabed areas. Stable areas, by these criteria, were located in the deep, low relief areas. Coarse-grained material that was deficient of fines and worm tubes was located on the shallow pinnacles of linear ridges. These were interpreted as being relatively unstable areas. The intermediate depths between ridge pinnacles and deep swales illustrated features of both stable quiescence and unstable turbulence. During the June survey period, 70% of the samples had either worm tubes or surface muds. During the September survey period (which was preceded by three storms), these same stations no longer had worm tubes or surface muds. It is apparent that processes capable of surface mud removal and worm tube scour were active during this four month interval.

The degree of near-surface bed stability (surface to -20 cm) was ultimately determined using the four different types of sedimentary analysis in a hierarchial matrix. Structural criteria was considered of primary impor-

tance, followed by the sorting and skewness criteria, textural criteria, and modal frequency criteria. A summation of these criteria resulted in an overall stability classification of an area. The June and September data sets were all fit into this overall stability classification (tables 21 and 22). The distributions of stability, based on the overall classification, were plotted on appropriate bathymetric maps for respective sampling periods (figures 25 and 26).

In June, three groups emerged relative to bathymetric features. Areas that were classified as moderately unstable (IV), unstable (V), and very unstable (VI) were all located along ridge crests or on ridge pinacles. Thus, during June, which represented a seasonally low energy period of time, there was still sufficient energy along ridge crests and pinnacles to prevent fine-grained sediment accumulation and/or preservation of biogenic structures.

The second obvious group was the very stable (I) area in the deep, low relief swale between ridges. The seabed was characterized by fine-grained sediment accumulation and preservation of numerous types of biogenic structures.

The third group represented an area containing a stable (II) and moderately stable (III) seabed. While the area was always located between deep and shallow regions, it was narrowest in high relief areas and broadest between terminal channels or ramps. The high relief areas were generally between pinnacles while terminal channels were located between ridges.

Seabed stability in September was similar to that in June. However, several obvious distinctions were recognized and related to the influence of relatively high energy conditions. Between June and September, 1982, moderately unstable (IV), unstable (V), and very unstable (VI) regions increased in area to include most of the ridge crests and ramps between ridges and low relief areas. This increase in unstable area was primarily at the expense of unclassified areas as well as moderately stable (III) and stable (II) areas. A small moderately stable (III) and stable (II) area still existed in an apparently well shielded terminal channel at the distal end of the funnel-shaped swale. The previously (June) very stable (I) area was unaffected by the increase in local energy. The deep, low relief region in

the swale between ridges remained very stable by all classification criteria.

The general findings of this survey indicate that NODS does not have a spatially and temporally homogeneous seabed with respect to stability. The surfaces of pinnacles on ridges may be unstable during the most quiescent summer periods. Fine-grained material winnowed from these areas apparently migrates down slope and accumulates in the relatively deep and shielded areas between ridges. Therefore, as winnowed areas, ridges and pinnacles tend to become coarser and slightly negatively skewed. As receiving areas, swales and low relief, deep areas tend to become finer and positively skewed.

DIVER RECONNAISSANCE OF MAGNETOMETER ANOMALIES

Between August 16 and 20, 1982, personnel from ODU participated in a number of Scuba dive surveys. Dives were made at precise locations determined by anomalies from magnetometer surveys conducted from May 12-16, 1982. Eleven targets were surveyed and descriptions of findings appear on the disposition form dated August 23, 1982 (Appendix IV). Diving operations were successful and provided the necessary data to the Environmental Analysis Branch, Norfolk District, U.S. Army Corps of Engineers.

Table 1

COE FINAL REPORTS
DACW65-81-C-0051

Work Order 0007	Work Order 0008 Part #2
Bottom Stability	Evaluate Bottom Conditions
1) 40 non commercial Benthic samples 20 Spring (April) 20 Fall (September)	1) 20 non commercial Benthic samples 20 Fall (>20 cm penetration)
2) Evaluation Radiography Radiometric dating	2) Evaluation Radiography (20 cm to penetration limit) Radiometric dating (20 cm to penetration limit)
3) Bottom topography (1 square mile at center disposal area)	3) Bottom topography (64 square miles at disposal area)
4) Estimate Bottom Stability for; short term (6 months) Intermediate periods (1 to 10 years) Long periods (30 to 150 years)	4) Grain Size Analysis
	5) Diver reconnaissance of magnetometer anomalies

Table 2

Station Locations and Water Depths

June 23, 1982

Station #	Location	Water Depth
ODS-1	(TD-X) 27095.25 (TD-Y) 41354.11	66'
ODS-2	27095.24 41350.42	59'
ODS-3	27095.18 41348.39	64'
ODS-4	27095.34 41345.61	59'
ODS-5	27094.00 41345.24	69'
ODS-6	27094.09 41348.65	68'
ODS-7	27094.00 41351.03	70'
ODS-8	27094.57 41353.03	69'
ODS-9	27093.36 41354.49	71'
ODS-10	27093.38 41347.04	74'
ODS-11	27092.10 41344.51	66'
ODS-12	27092.05 41348.68	66'

Table 2 (concluded)

Station #	Location	Water Depth
ODS-13	27092.03 41350.93	73'
ODS-14	27092.10 41354.33	72'
ODS-15	27091.46 41352.65	75'
ODS-16	27091.49 41347.76	71'
ODS-17	27090.52 41346.05	63'
ODS-18	27090.77 41348.51	64'
ODS-19	27090.86 41352.81	67'
ODS-20	27090.02 41355.34	75'

Table 3

Station Locations and Water Depths

September 16, 1982

Station #	Location	Water Depth
ODS-1	27095.20 41354.50	67'
ODS-2	27095.20 41350.50	60'
ODS-3	27095.20 41348.50	64'
ODS-4	27095.12 41345.60	58'
ODS-5	27094.00 41345.50	68'
ODS-6	27094.12 41348.65	65'
ODS-7	27094.00 41351.00	69'
ODS-8	27094.60 41353.00	67'
ODS-9	27093.40 41354.70	68'
ODS-10	27093.30 41347.55	72'
ODS-11	27092.12 41344.50	65'
ODS-12	27092.23 41348.55	67'

Table 3 (concluded)

Station Locations and Water Depths

September 16, 1982

Station #	Location	Water Depth
ODS-13	27092.19 41351.00	72'
ODS-14	27092.10 41354.10	71'
ODS-15	27091.50 41352.60	72'
ODS-16	27091.50 41347.20	68'
ODS-17	27090.48 41346.10	64'
ODS-18	27091.00 41348.50	68'
ODS-19	27090.80 41352.70	72'
ODS-20	27089.90 41355.45	74'

Table 4. Sample data sheet used in analysis of primary and secondary sedimentary structures in x-ray radiographs.

	PHYSICAL STRUCTURES				BIOGENIC STRUCTURES					
							BURROWS and DWELLING TUBES			
SAMPLE NO.	RIPPLE FORESETS	INTERMED. FORESETS	HORIZONTAL LAMINAE	TABULAR TEXTURAL BEDS	MICRO-LOCOMOTION	MACRO-LOCOMOTION	VERTICAL	INCLINED	TUBE WIDTH	UNKNOWN

Table 5

June 23, 1982

Textural Analysis

Sample Number	Percent Sand	Percent Silt	Percent Clay	*Mean	*Sorting	*Skewness	*Kurtosis
1	98.83	0.11	1.06	0.77ϕ	1.07ϕ	-0.08	1.31
2	98.91	0.44	0.65	1.26ϕ	1.13ϕ	-0.31	1.40
3	98.29	0.21	1.50	2.35ϕ	0.60ϕ	0.05	1.04
4	98.73	0.16	1.11	2.49ϕ	0.51ϕ	0.06	1.04
5	98.17	0.60	1.23	2.54ϕ	1.20ϕ	-0.63	1.20
6	98.19	0.67	1.14	2.87ϕ	0.64ϕ	-0.25	1.29
7	97.90	0.97	1.13	3.06ϕ	0.49ϕ	-0.24	1.34
8	98.64	0.48	0.88	2.99ϕ	0.48ϕ	-0.14	1.21
9	97.79	1.01	1.20	3.05ϕ	0.57ϕ	-0.33	1.56
10	97.65	1.22	1.13	0.72ϕ	2.02ϕ	0.28	0.64
11A	99.07	0.09	0.84	0.94ϕ	1.10ϕ	-0.19	1.64
11B	94.88	2.07	3.05	2.97ϕ	0.67ϕ	-0.15	1.56

*Graphic Statistical Parameters

Table 5 (concluded)

June 23, 1982

Textural Analysis

Sample Number	Percent Sand	Percent Silt	Percent Clay	*Mean	*Sorting	*Skewness	*Kurtosis
12	98.63	0.17	1.20	0.40ϕ	1.66ϕ	-0.35	1.31
13	97.07	1.25	1.68	3.20ϕ	0.37ϕ	0.09	1.50
14	95.44	2.17	2.39	3.13ϕ	0.41ϕ	0.05	1.21
15	94.24	3.21	2.55	3.28ϕ	0.41ϕ	0.18	1.88
16	97.19	1.21	1.60	2.91ϕ	0.75ϕ	-0.48	1.58
17A	98.35	0.07	1.58	1.88ϕ	0.73ϕ	-0.04	1.07
17B	97.49	0.16	2.35	2.02ϕ	1.24ϕ	-0.39	1.74
18	96.89	0.29	2.82	2.17ϕ	1.00ϕ	-0.18	1.91
19	98.72	0.31	0.97	2.66ϕ	0.61ϕ	-0.16	0.95
20	96.28	1.50	2.22	3.26ϕ	0.31ϕ	0.03	1.51

*Graphic Statistical Parameters

Table 6

September 16, 1982

Textural Analysis

Sample Number	Percent Sand	Percent Silt	Percent Clay	*Mean	*Sorting	*Skewness	*Kurtosis
1A	95.96	0.07	3.97	0.82ϕ	1.22ϕ	-0.09	1.20
1B	96.87	0.06	3.08	1.65ϕ	0.91ϕ	-0.17	1.21
2	97.99	0.11	1.90	0.94ϕ	1.03ϕ	0.12	1.25
3	98.42	0.15	1.42	1.98ϕ	0.74ϕ	-0.06	1.28
4	98.46	0.14	1.40	2.28ϕ	0.59ϕ	0.05	1.07
5	96.03	1.68	2.30	2.35ϕ	1.37ϕ	-0.63	0.86
6	97.95	0.89	1.16	2.79ϕ	0.62ϕ	-0.13	1.24
7	99.10	0.24	0.66	0.61ϕ	1.19ϕ	0.03	1.15
8	99.39	0.11	0.49	0.76ϕ	1.24ϕ	-0.02	1.11
9	97.24	1.59	1.18	3.11ϕ	0.53ϕ	-0.32	1.84
10A	99.32	0.21	0.46	0.30ϕ	1.10ϕ	0.13	1.30
10B	98.47	0.69	0.84	1.51ϕ	1.62ϕ	-0.26	1.08

Table 6 (concluded)

Textural Analysis

September 16, 1982

Sample Number	Percent Sand	Percent Silt	Percent Clay	*Mean	*Sorting	*Skewness	*Kurtosis
10C	24.86	37.53	37.61	6.86ϕ	4.19ϕ	0.06	0.89
11	98.81	0.09	1.10	1.26ϕ	0.89ϕ	-0.22	1.48
12	98.89	0.03	1.08	0.48ϕ	1.28ϕ	-0.28	1.40
13	96.56	1.58	1.86	3.26ϕ	0.31ϕ	0.03	1.51
14	93.36	4.37	2.27	3.25ϕ	0.47ϕ	0.14	1.97
15	94.77	2.88	2.35	3.31ϕ	0.36ϕ	0.17	1.61
16	98.66	0.17	1.17	2.18ϕ	0.80ϕ	-0.04	1.19
17A	98.36	0.11	1.53	1.90ϕ	0.72ϕ	-0.05	1.18
17B	99.87	0.01	0.12	1.25ϕ	1.32ϕ	-0.29	1.73
18	98.58	0.17	1.25	0.17ϕ	1.11ϕ	-0.06	1.93
19	98.72	0.12	1.16	2.19ϕ	0.72ϕ	0.15	0.92
20	95.01	2.82	2.17	3.30ϕ	0.34ϕ	0.12	1.49

*Graphic Statistical Parameters

Table 7

Sediment Size Categories

(Expressed as percentages)

June 23, 1982

Sample Number	Sample Depth(cm)	Coarse (4mm-1/2mm)	Medium Sand (<1/2mm-1/4mm)	Fine Sand (<1/4mm-1/16mm)	Silt and Clay (<1/16mm)
1	15-20	61.22	29.86	7.75	1.17
2	10-15	36.53	43.18	19.20	1.09
3	8-13	2.00	23.65	72.64	1.71
4	5-9	0.53	13.52	84.68	1.27
5	5-10	14.43	12.03	71.71	1.83
6	6-12	1.85	10.60	85.74	1.81
7	9-14	1.85	3.62	92.43	2.10
8	5-10	2.55	2.91	93.18	1.36
9	6-11	2.86	6.07	88.86	2.21
10	4-10	62.11	3.26	32.28	2.35
11A	8-13	50.69	41.94	6.44	0.93
11B	17-19	4.02	4.25	86.61	5.12
12	6-11	58.31	31.40	8.92	1.37
13	7-12	1.24	2.80	93.03	2.93
14	10-14	0.79	1.90	92.75	4.56
15	12-17	0.27	1.55	92.42	5.76
16	11-16	4.65	9.58	82.96	2.81
17A	5-10	11.53	46.66	40.16	1.65
17B	12.5-15	16.20	25.95	55.34	2.51
18	8-13	8.30	35.04	53.55	3.11
19	6-11	1.49	14.82	82.41	1.28
20	5-10	0.26	0.72	95.31	3.72

Table 8

Sediment Size Categories

(Expressed as percentages)

September 16, 1982

Sample Number	Sample Depth (cm)	Coarse (4mm-1/2mm)	Medium Sand (<1/2mm-1/4mm)	Fine Sand (<1/4mm-1/16mm)	Silt & Clay (<1/16mm)
1A	2-7	54.48	33.12	8.36	4.04
1B	14-19	20.89	45.40	30.58	3.13
2	7-13	56.75	30.27	10.97	2.01
3	8-14	10.47	39.67	48.28	1.58
4	6-12	2.46	27.03	68.97	1.54
5	5-10	22.66	9.23	64.14	3.97
6	5-11	1.74	8.87	87.34	2.05
7	5-10	65.41	23.65	10.04	0.90
8	5-10	58.98	27.27	13.14	0.61
9	5-10	2.57	4.21	90.46	2.76
10A	2-7	77.98	15.29	6.05	0.68
10B	12-16	36.32	22.99	39.16	1.53
10C	16-23	10.55	3.54	10.77	75.14
11	5-10	34.40	54.83	9.58	1.19
12	5-10	66.46	27.21	5.22	1.11
13	5-10	0.44	.70	95.42	3.44
14	5-10	0.66	1.12	91.58	6.64
15	5-10	0.32	0.49	93.96	5.23
16	5-10	9.36	33.11	56.19	1.34
17A	3-9	10.37	47.18	40.81	1.64
17B	12-17	32.17	44.85	22.85	0.13
18	3-9	88.14	5.43	5.01	1.42
19	3-9	4.66	41.82	52.24	1.28
20	5-10	0.24	0.31	94.46	4.99

Table 9

Grain Texture Stability Index

MOST STABLE	(> 2% silt and clay,	> 60% fine sand,	< 4% coarse)	MS-I
Decreasing ↓	(> 2% " "	> 60% " ",	> 4% ")	MS-II
Stability ↓	(< 2% " "	> 60% " ",	< 4% ")	MS-III
↓	(< 2% " "	> 60% " ",	> 4% ")	
	(> 2% " "	< 60% " ",	< 4% ")	
	(> 2% " "	< 60% " ",	> 4% ")	
	(< 2% " "	< 60% " ",	< 4% ")	MS-IV
	(< 2% " "	< 60% " ",	> 4% ")	

Table 10

LEAST STABLE	(> 60% Coarse,	< 10% fine sand,	< 1.5% silt + clay)	LS-I
Increasing ↓	(> 60% " ,	< 10% " " ,	> 1.5% " ")	LS-II
Stability ↓	(> 60% " ,	> 10% " " ,	< 1.5% " ")	LS-III
↓	(> 60% " ,	> 10% " " ,	> 1.5% " ")	
	(< 60% " ,	< 10% " " ,	< 1.5% " ")	
	(< 60% " ,	< 10% " " ,	> 1.5% " ")	
	(< 60% " ,	> 10% " " ,	< 1.5% " ")	LS-IV
	(< 60% " ,	> 10% " " ,	> 1.5% " ")	

Table 11

Textural Stability
June 23, 1982

Sample Number	MS-I	MS-II	MS-III	MS-IV	LS-I	LS-II	LS-III	LS-IV
1				x	x			
2				x				x
3			x					x
4			x					x
5			x					x
6			x					x
7	x							x
8			x					x
9	x							x
10				x			x	
11A				x				x
11B		x						x
12				x				x
13	x							x
14	x							x
15	x							x
16		x						x
17A				x				x
17B				x				x
18				x				x
19			x					x
20	x							x

Table 12

Textural Stability
September 16, 1982

Sample Number	MS-I	MS-II	MS-III	MS-IV	LS-I	LS-II	LS-III	LS-IV
1A				x				x
1B				x				x
2				x				x
3				x				x
4			x					x
5		x						x
6	x							x
7				x	x			
8				x				x
9	x							x
10A				x	x			
10B				x				x
10C				x				x
11				x				x
12				x	x			
13	x							x
14	x							x
15	x							x
16				x				x
17A				x				x
17B				x				x
18				x	x			
19								x
20	x							x

Table 13
Sorting/Skewness Stability Criteria

S-I - < .50ϕ (sorting), > .10 (skewness)
Extremely Stable

Representative Samples: June 23, 1982 - 15, 20
September 16, 1982 - 14, 15, 20

S-II - < .50ϕ (sorting), < .10 to - .10 (skewness)
Stable

Representative Samples: June 23, 1982 - 13, 14
September 16, 1982 - 13

S-III - < .50ϕ (sorting) < - .10 (skewness)
Moderately Stable

Representative Samples: June 23, 1982 - 7, 8
September 16, 1982

Table 14

Sorting/Skewness Instability Criteria

U - I - > 1.0ϕ (sorting), < - .10 (skewness)
Extremely Unstable

Representative Samples: June 23, 1982 - 2, 5, 11A, 12, 17B, 18
September 16, 1982 - 5, 10B, 12, 17B

U - II - > 1.0ϕ (sorting), > - .10 to .10 (skewness)
Unstable

Representative Samples: June 23, 1982 - 1
September 16, 1982 - 1A, 7, 8, 10C, 18

U - III - > 1.0ϕ (sorting), > .10 (skewness)
Moderately Unstable

Representative Samples: June 23, 1982 - 10
September 16, 1982 - 2, 10A

Table 15

Modal Frequency (ϕ units) June 23, 1982

Sample Number	1st Mode	2nd Mode	3rd Mode	4th Mode
1	0.77	-	-	-
2	1.71	-	-	-
3	2.30	-	-	-
4	2.42	-	-	-
5	3.21	1.75[1]	0.91[1]	-1.37[2]
6	3.08	1.98[1]	-	-
7	3.17	-	-	-
8	3.05	-	-	-
9	3.20	1.91[2]	-2.66[3]	-
10	3.22	-0.25	-	-
11A	0.87	1.53	2.63[2]	-
11B	3.05	0.82[2]	-	-
12	0.85	2.68[1]	-1.81[2]	-
13	3.24	1.74[2]	-	-
14	3.20	1.92[2]	-	-
15	3.25	1.75[2]	-	-
16	3.22	1.90[1]	-	-
17A	1.82	-	-	-
17B	2.60	-	-	-
18	1.94	-1.70[2]	-	-
19	2.80	0.29[3]	-	-
20	3.25	1.74	-	-

1 - mode represents > 5% but < 10% of population
2 - mode represents > 1% but < 5% of population
3 - mode represents < 1% of population

Table 16
Modal Frequency (in ϕ units)
September 16, 1982

Sample Number	1st Mode	2nd Mode	3rd Mode
1A	0.81	1.55	-
1B	1.79	-	-
2	0.76	2.74[1]	-
3	2.0	-	-
4	2.25	-	-
5	3.21	0.78[1]	-1.6[2]
6	2.86	-1.81[3]	-
7	0.72	2.72[2]	-
8	0.69	-	-
9	3.22	1.93[2]	-
10A	0.53	3.15[2]	-
10B	2.77	1.72	0.88
10C	5.81	2.90	0.62
11	1.61	-	-
12	0.79	-1.64[2]	2.59[2]
13	3.25	-	-
14	3.24	-	-
15	3.26	-	-
16	1.99	-1.67[3]	-
17A	1.83	-	-
17B	1.36	-1.92[2]	-2.54[2]
18	0.34	-1.73[2]	2.93[2]
19	1.82	2.50	-
20	3.26	-	-

1 - Mode represents > 5% but < 10% of the population
2 - Mode represents > 1% but < 5% of the population
3 - Mode represents < 1% of the population

Table 17

Modal Frequency Stability Criteria

S - I → Stable: primary mode > 2.75ϕ with no significant secondary mode

Representative Samples: June 23, 1982 - 7, 8, 9, 11B, 13, 14, 15, 19, 20
September 16, 1982 - 6, 9, 13, 14, 15, 20

S - II → Mostly Stable: primary mode > 2.75ϕ with one coarser secondary mode > 5% but < 10% of population

Representative Samples: June 23, 1982 - 5, 16
September 16, 1982 - 5

U - I → Unstable: primary mode < 1ϕ with no significant secondary modes

Representative Samples: June 23, 1982 - 1
September 16, 1982 - 7, 8, 10A, 12, 18

U - II → Mostly Unstable: primary mode < 1ϕ with one finer secondary mode > 5% but < 10% of population

Representative Samples: June 23, 1982 - 12
September 16, 1982 - 2

Table 18

Physical and Biogenic Sedimentary Structure
Stability Index

INCREASING STABILITY

I - Intermediate Foresets/Horizontal Laminae

II - Ripple Foresets and Cross-bedding

III - Tabular Beds

IV - Macro-locomotion bioturbation

V - Deep Vertical burrows & Dwelling Tubes

VI - Shallow Vertical burrows & Dwelling Tubes

VII - Shallow Inclined Dwelling Tubes

VIII - Micro - locomotion bioturbation

IX - Unknown

Unstable	I, II
Moderately Unstable	III, IV
Moderately Stable	IV, V
Stable	VI, VII, VIII

Table 19

Sedimentary Structure Stability Criteria
June 23, 1982

Sample Number	Surface	> Surface - 10cm	> 10cm - 20cm	> 20cm
1	IX, VII	I	I	IX
2	IV	IV	I, VIII	I, VIII
3	I	I	VIII, I	-
4	I	I	I	-
5	VI, VIII	VI, V, VIII	VIII	-
6	II, VIII, VI	VIII, VI, V	VIII, V	-
7	VIII, VI	VIII, VI, V	VIII, V	-
8	II	IV, I(bottom)	VIII, I (top)	-
9	VIII, VI	VIII, VI, V	VIII, V	-
10	VI, IX	VI, V, IX	V,IX	-
11	IX	IX	IX	-
12	IX	IX	IX	-
13	VIII, VI, III	VIII, VI, V, III	III, VIII, V	III
14	VIII, VI	VIII, VI, V	VIII	-
15	VIII, VI	VIII, VI, V	VIII, V	VIII, V
16	VIII, VI	VIII, VI, V	VIII, IV	VIII, IV
17	IX	I	I, IX	-
18	VIII, IV	I	VIII	-
19	I	I, VIII	VIII	-
20	VIII, VI	VIII, VI, V	VIII, V	-

Table 20

Sedimentary Structure Stability Criteria
September 16, 1982

Sample Number	Surface	> Surface - 10cm	> 10cm - 20cm	> 20cm
1	IX	IX	I	I
2	IX	IX, I	IX, I	-
3	VIII	VIII, I	VIII, I	-
4	II	II, I	I, IX	-
5	IV, VI, III	IV, VI, V, III	I, III, V	-
6	VIII, IV, VI	VIII, IV, VI, V	VIII, IV, V	-
7	I, IX	I	I	IX
8	III	III	III	IX
9	VI	VIII	VIII	-
10	IX	IX	IX, IV	I
11	IX	IX, I	IX, I	-
12	IX, I	IX, I	IX, I	IX
13	VIII, VI	VIII, VI, V	VIII	-
14	VIII, VI, VII	VIII, VI, V	VIII	-
15	VIII, VI	VIII, VI, V	VIII, V	-
16	IX, VI	I, VI	I, VI	-
17	IX	IX	IV, III	-
18	IX	IX	IX	-
19	I	I	VIII	-
20	VIII, VI	VIII. VI, V	VIII, V	-

Table 21

Composite Stability Classification
June 23, 1983

Sample Number	Textural Criteria	Sorting/Skewness Criteria	Modal Frequency Criteria	Structural Criteria	Overall Classification
1	LS-I	U-II	U-I	Unstable	Very Unstable
2	*	U-I	*	M.Unstable	M.Unstable
3	MS-III	*	*	Unstable	M.Unstable
4	MS-III	*	*	Unstable	M.Unstable
5	MS-III	U-I	S-II	Stable	M.Stable
6	MS-III	*	S-II	Stable	Stable
7	MS-I	S-III	S-I	Stable	V.Stable
8	MS-III	S-III	S-I	M.Unstable	M.Stable
9	MS-I	*	S-I	Stable	V.Stable
10	LS-III	U-III	*	M.Stable	M.Stable
11A	*	U-I	*	*	*
11B	MS-II	*	S-I	*	Stable
12	*	U-I	U-II	*	Unstable
13	MS-I	S-II	S-I	Stable	V.Stable
14	MS-I	S-II	S-I	Stable	V.Stable
15	MS-I	S-I	S-I	Stable	V.Stable
16	MS-II	*	S-II	Stable	Stable
17A	*	*	*	Unstable	*
17B	*	U-I	*	Unstable	Unstable
18	*	U-I	*	M.Unstable	Unstable
19	MS-III	*	S-I	M.Unstable	M.Unstable
20	MS-I	S-I	S-I	Stable	V.Stable

*no recognizable trend in data

Table 22

Composite Stability Classification
September 16, 1982

Sample Number	Textural Criteria	Sorting/Skewness Criteria	Modal Frequency Criteria	Structural Criteria	Overall Classification
1A	*	U-II	*	*	M.Unstable
1B	*	*	*	Unstable	Unstable
2	*	U-III	U-II	Unstable	Unstable
3	*	*	*	Stable	Stable
4	MS-III	*	*	Unstable	M.Unstable
5	MS-II	U-I	S-II	M.Stable	M.Stable
6	MS-I	*	S-I	Stable	V.Stable
7	LS-I	U-II	U-I	Unstable	V.Unstable
8	*	U-II	U-I	M.Unstable	M.Unstable
9	MS-I	*	S-I	Stable	V.Stable
10A	LS-I	U-III	U-I	*	Unstable
10B	*	U-I	*	*	Unstable
10C	*	U-II	*	*	*
11	*	*	*	Unstable	Unstable
12	LS-I	U-I	U-I	Unstable	V.Unstable
13	MS-I	S-II	S-I	Stable	V.Stable
14	MS-I	S-I	S-I	Stable	V.Stable
15	MS-I	S-I	S-I	Stable	V.Stable
16	*	*	*	M.Unstable	M.Unstable
17A	*	*	*	*	*
17B	*	U-I	*	M.Unstable	Unstable
18	LS-I	U-II	U-I	*	Unstable
19	*	*	*	Unstable	Unstable
20	MS-I	S-I	S-I	Stable	V.Stable

*no recognizable trend in data

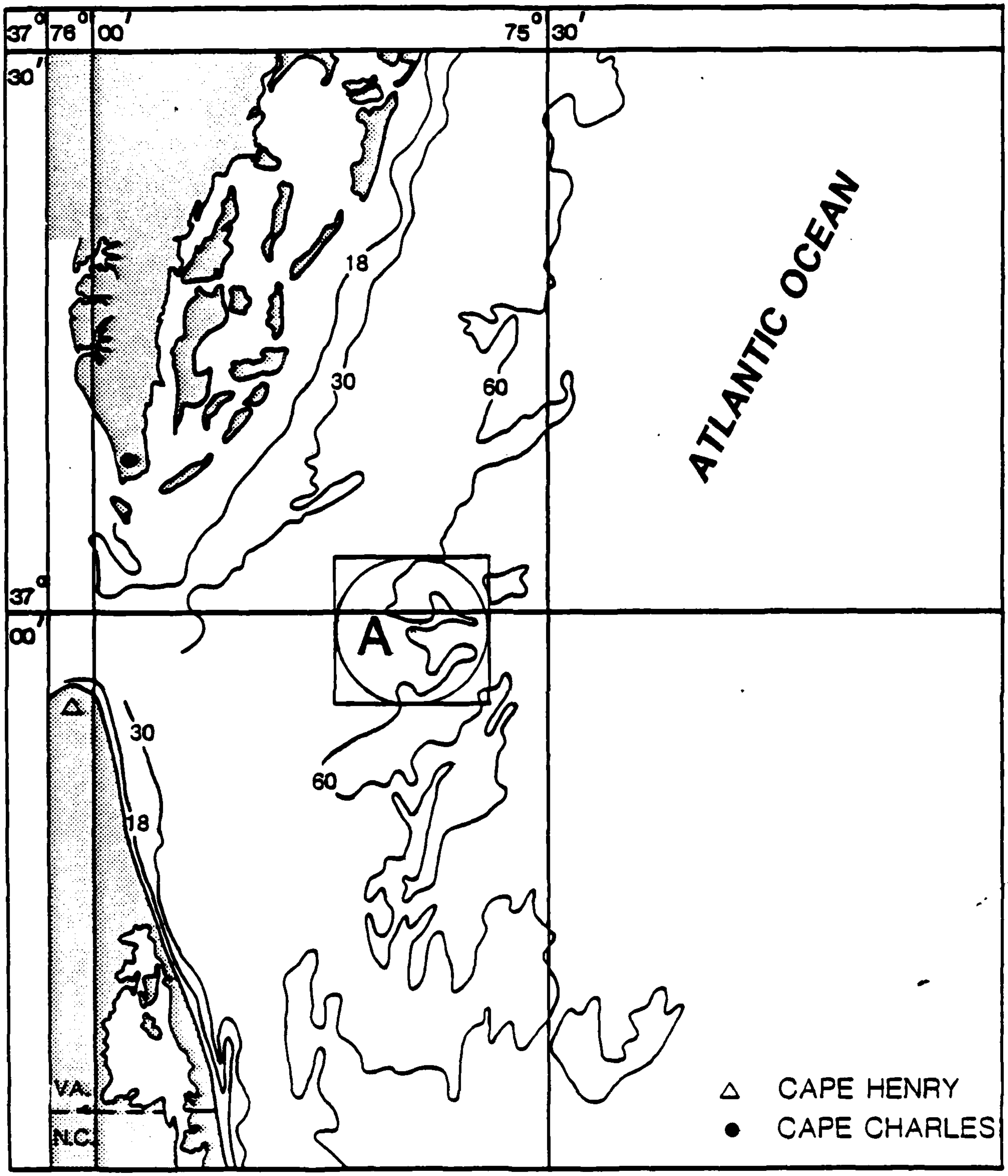

Figure 1. Location map of Norfolk Ocean Disposal Site (NODS). Circled area is the disposal site. Square area was used for bathymetric projection in figure 2.

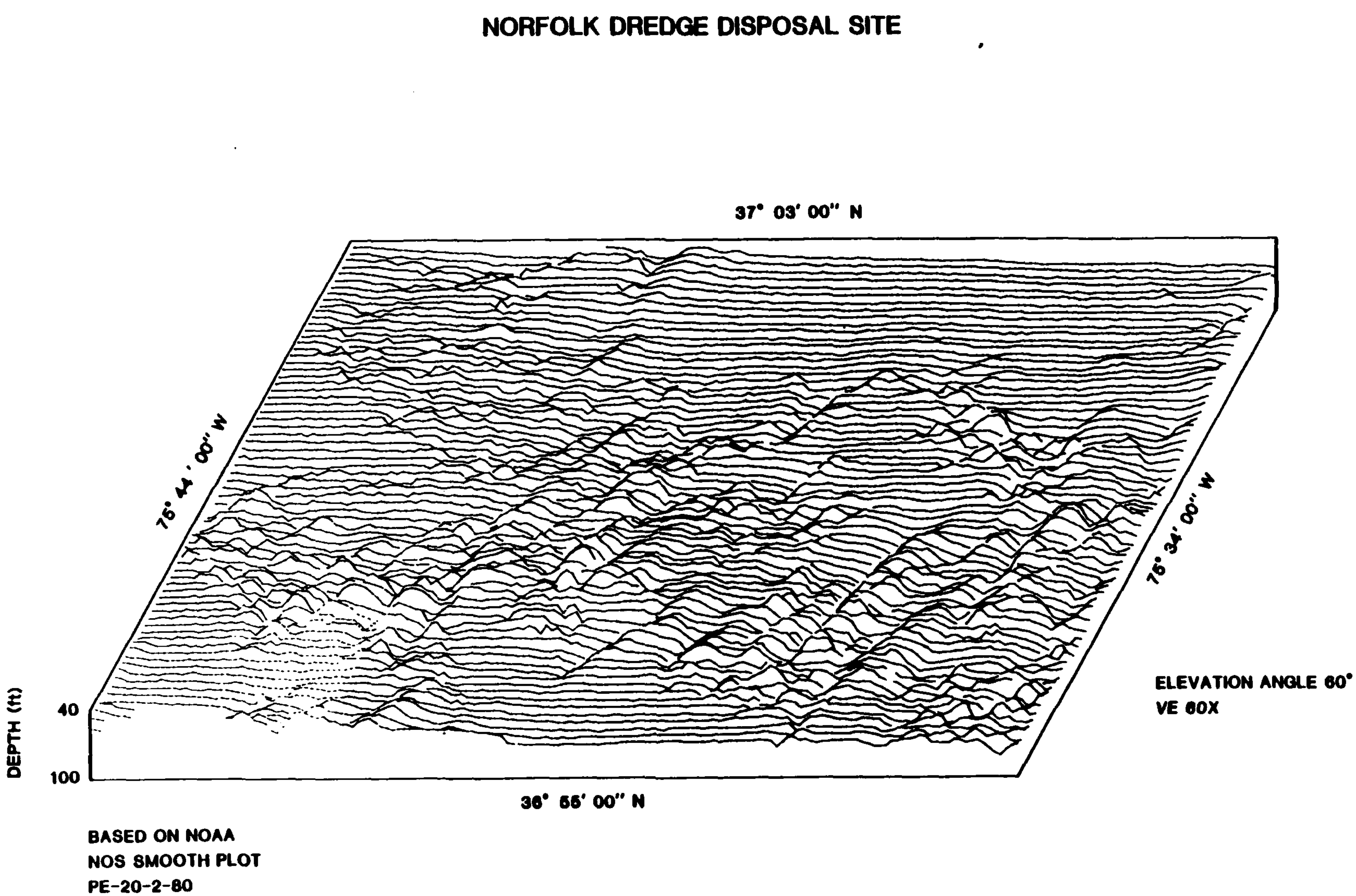

Figure 2. Bathymetric projection of 8 nautical mile by 8 nautical mile area of NODS centered around 35^0 59'N and 75^0 39'W.

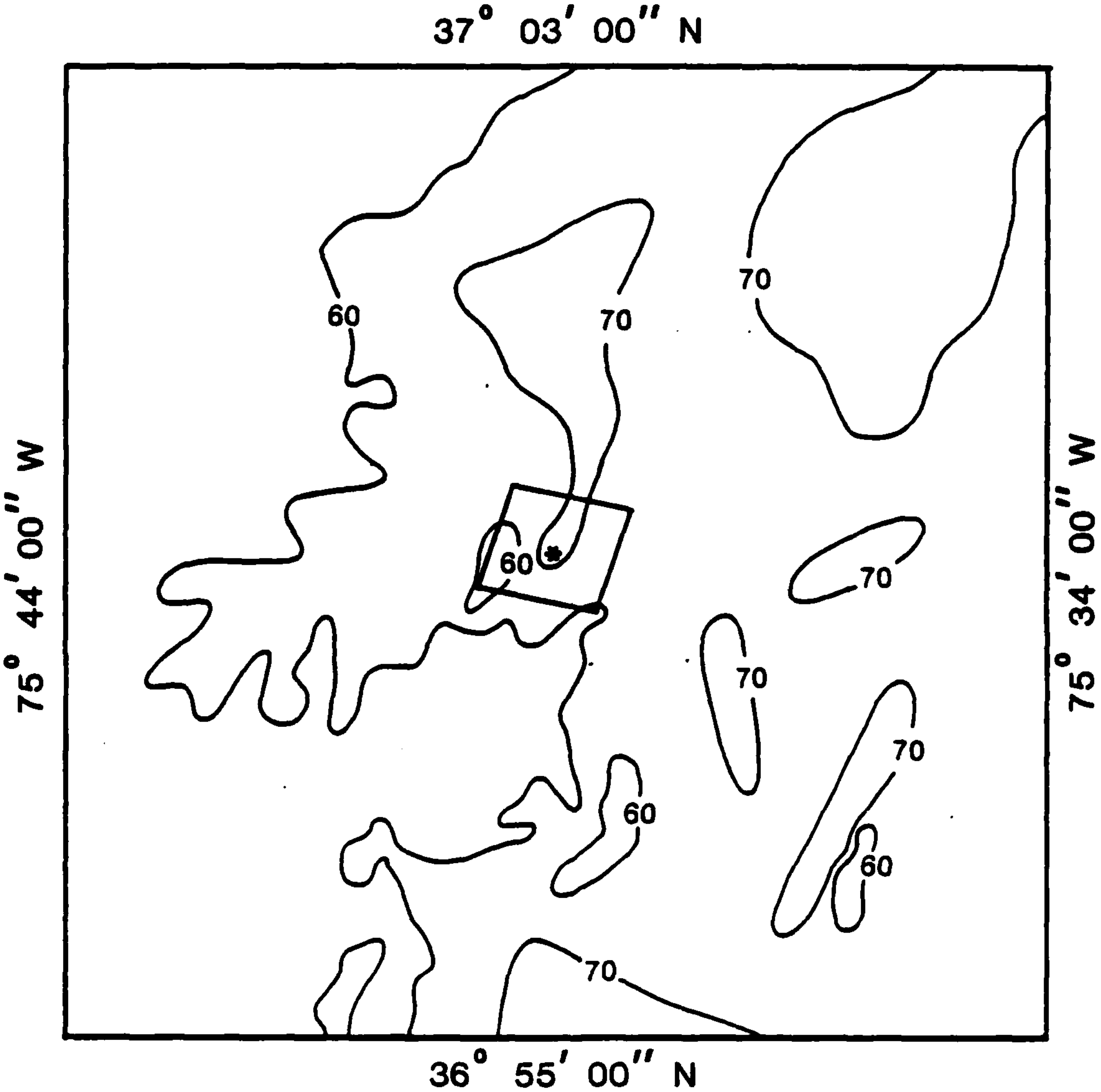

Figure 3. Location map of study area (approximately 1 square nautical mile) at the center of NODS.

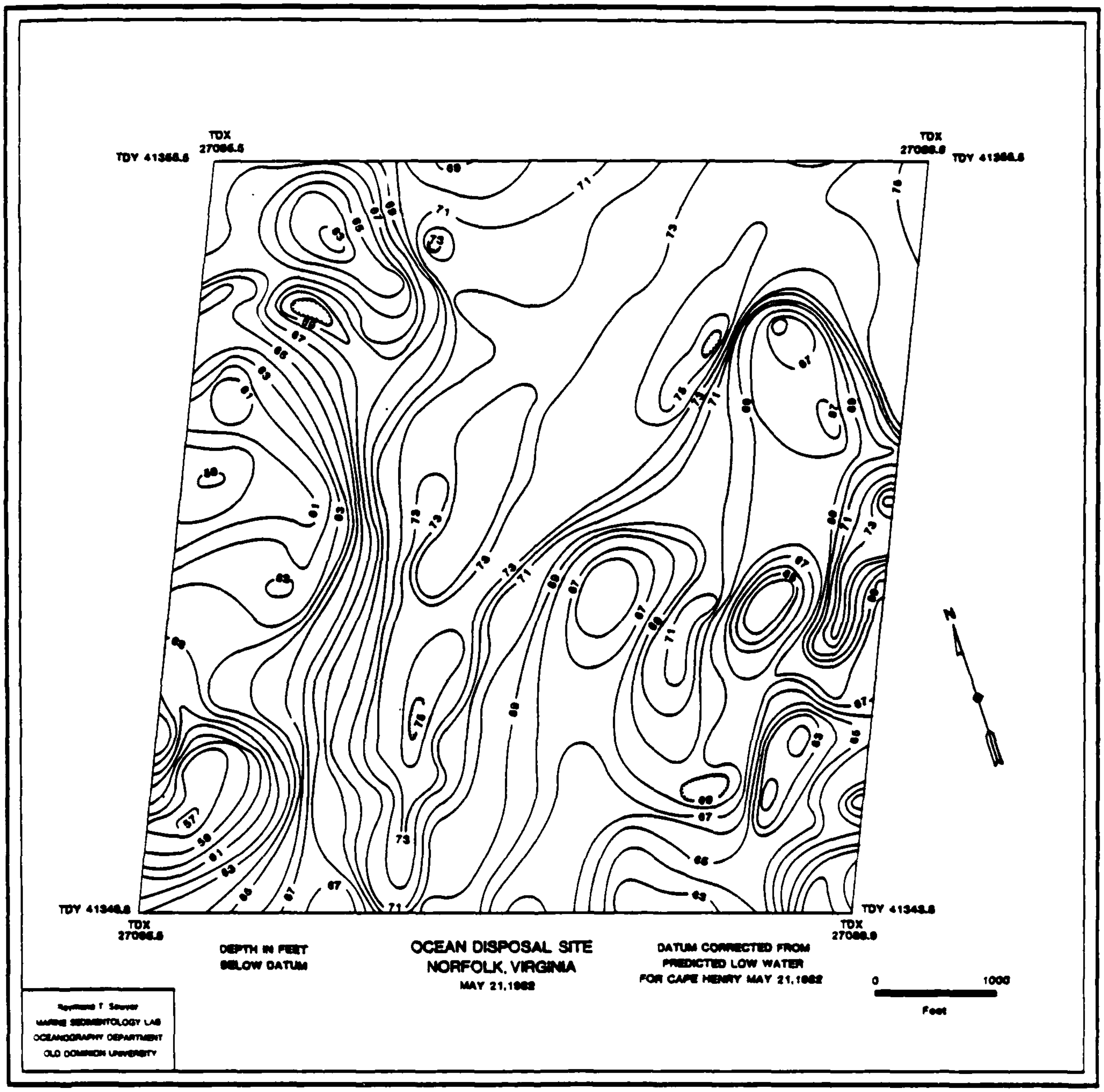

Figure 4. Bathymetric chart of study area based upon
May 1982 survey.

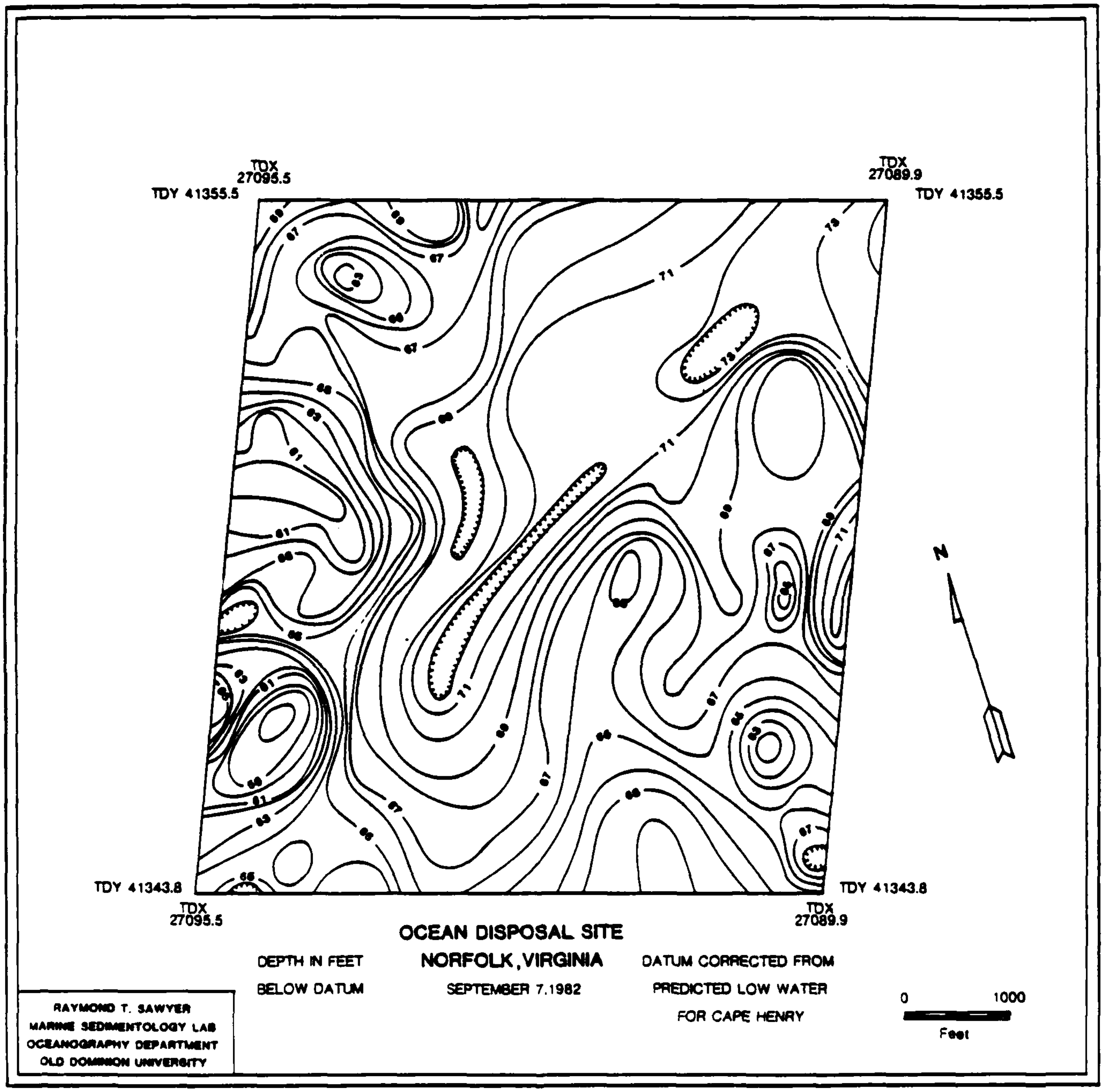

Figure 5. Bathymetric chart of study area based upon September 1982 survey.

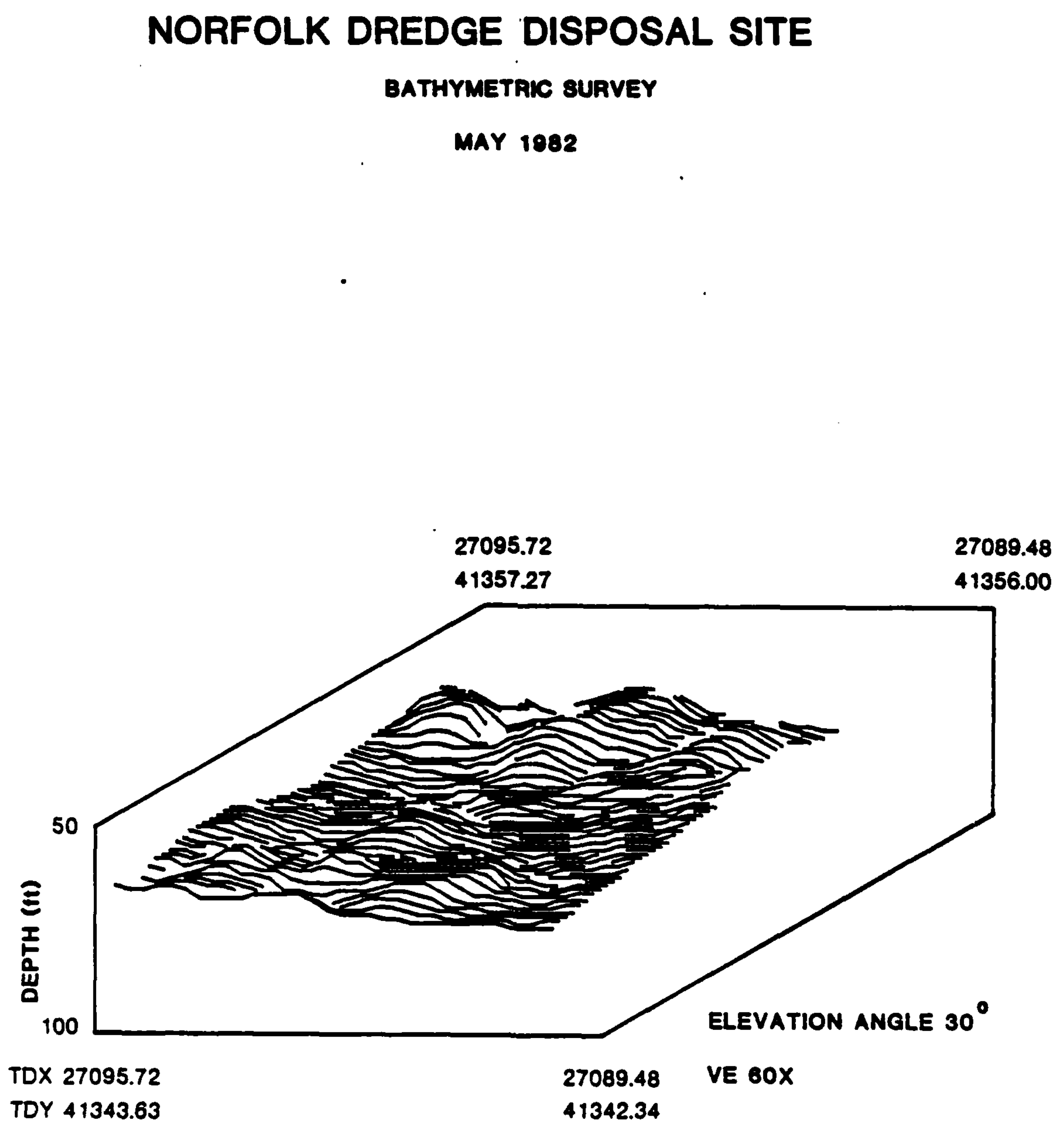

Figure 6. Bathymetric projection of study area, with a 30° projection angle. Projection based upon May 1982 data set.

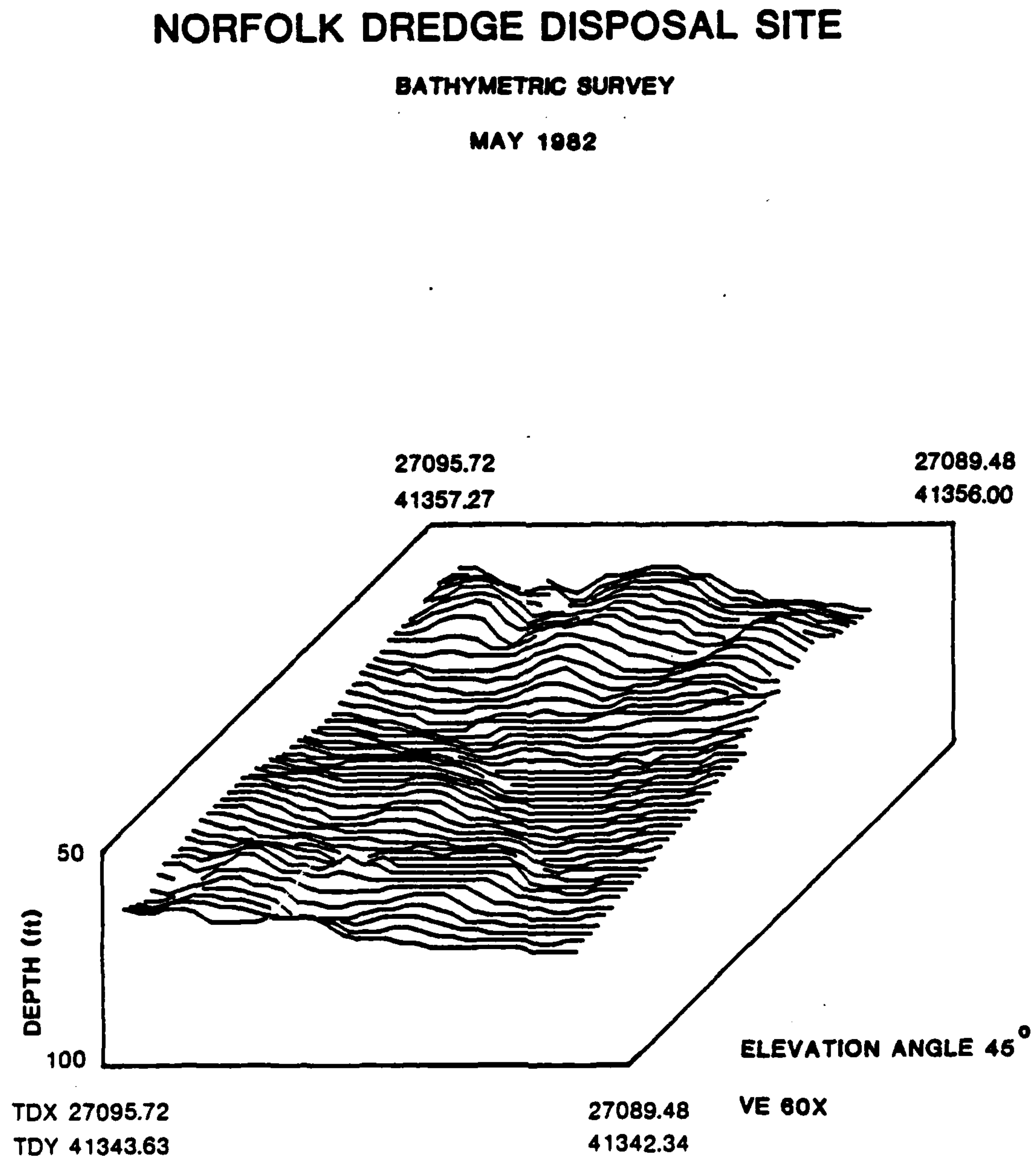

Figure 7. Bathymetric projection of study area, with a 45^0 projection angle. Projection based upon May 1982 data set.

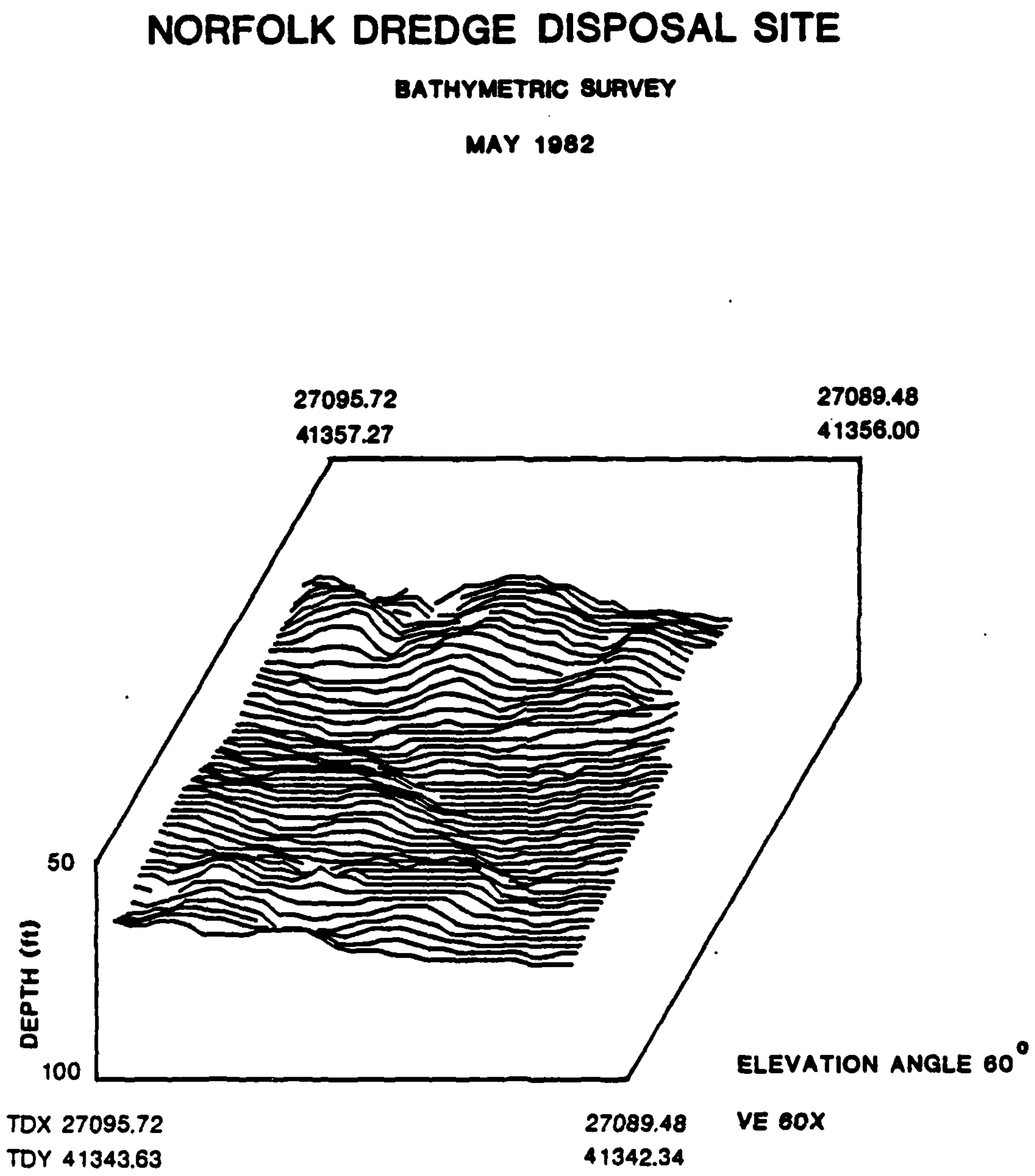

Figure 8. Bathymetric projection of study area, with a 60° projection angle. Projection based upon May 1982 data sheet.

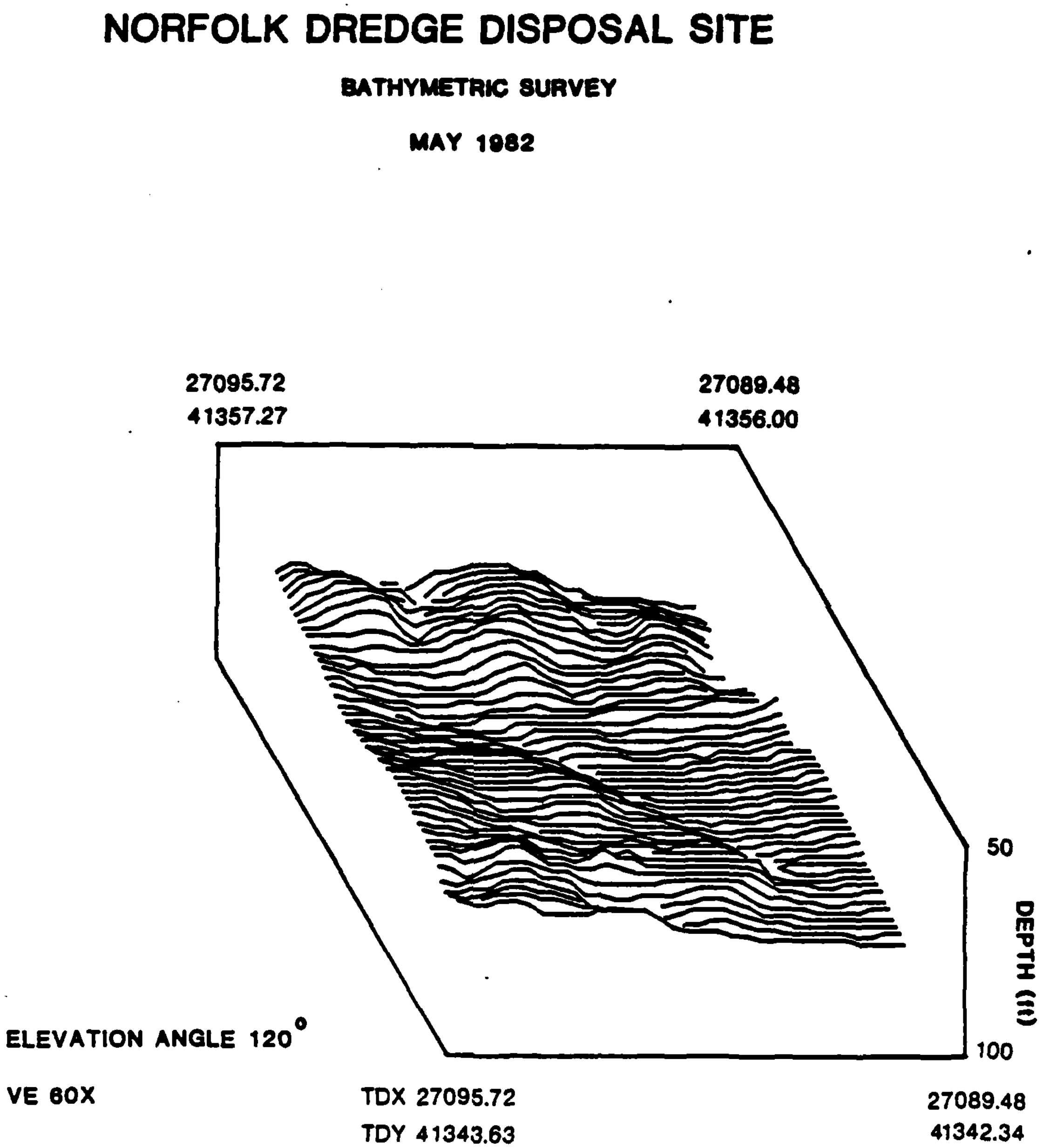

Figure 9. Bathymetric projection of study area, with a 120° projection angle. Projection based upon May 1982 data sheet.

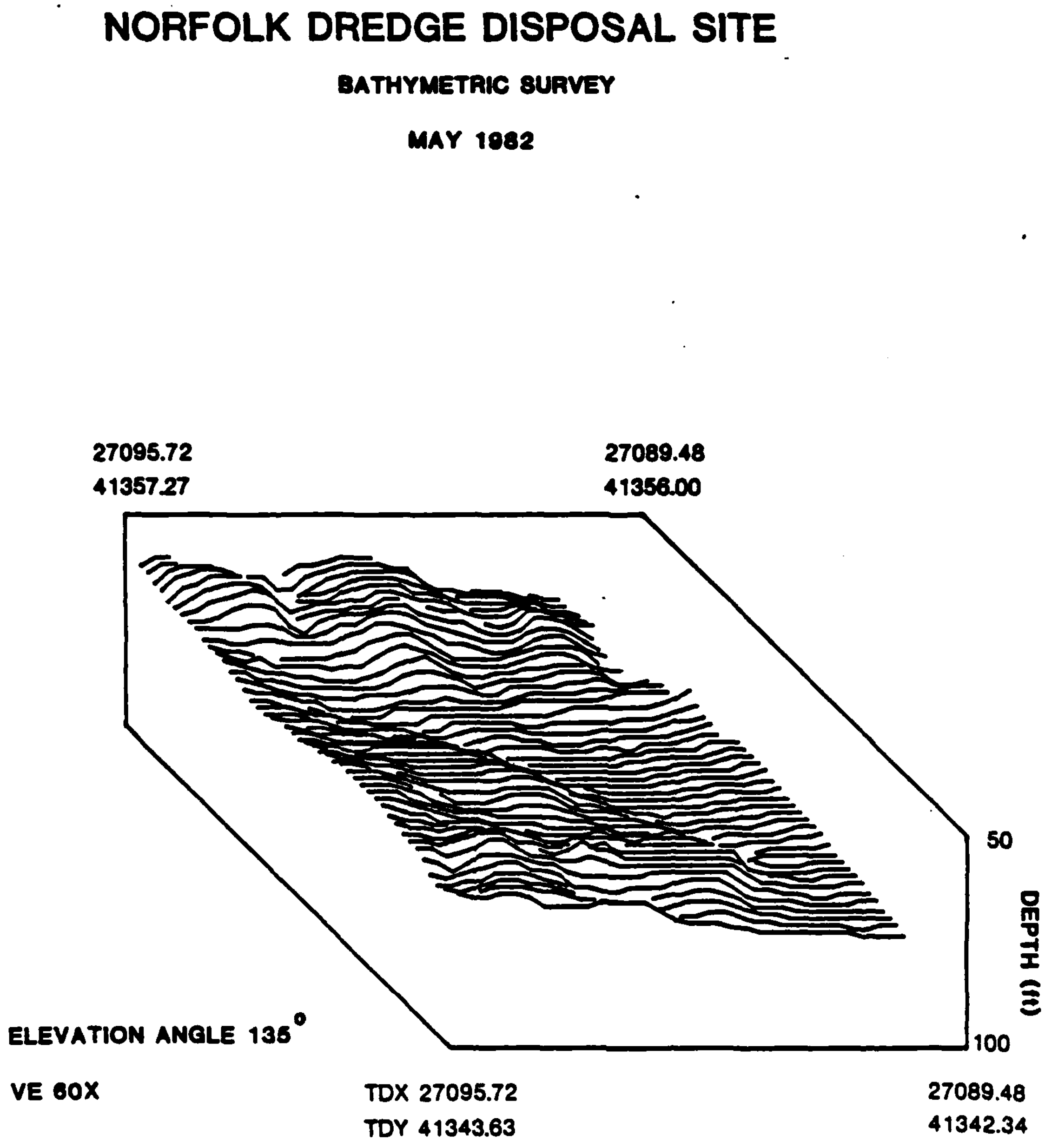

Figure 10. Bathymetric projection of study area, with a 135^0 projection angle. Projection based upon May 1982 data set.

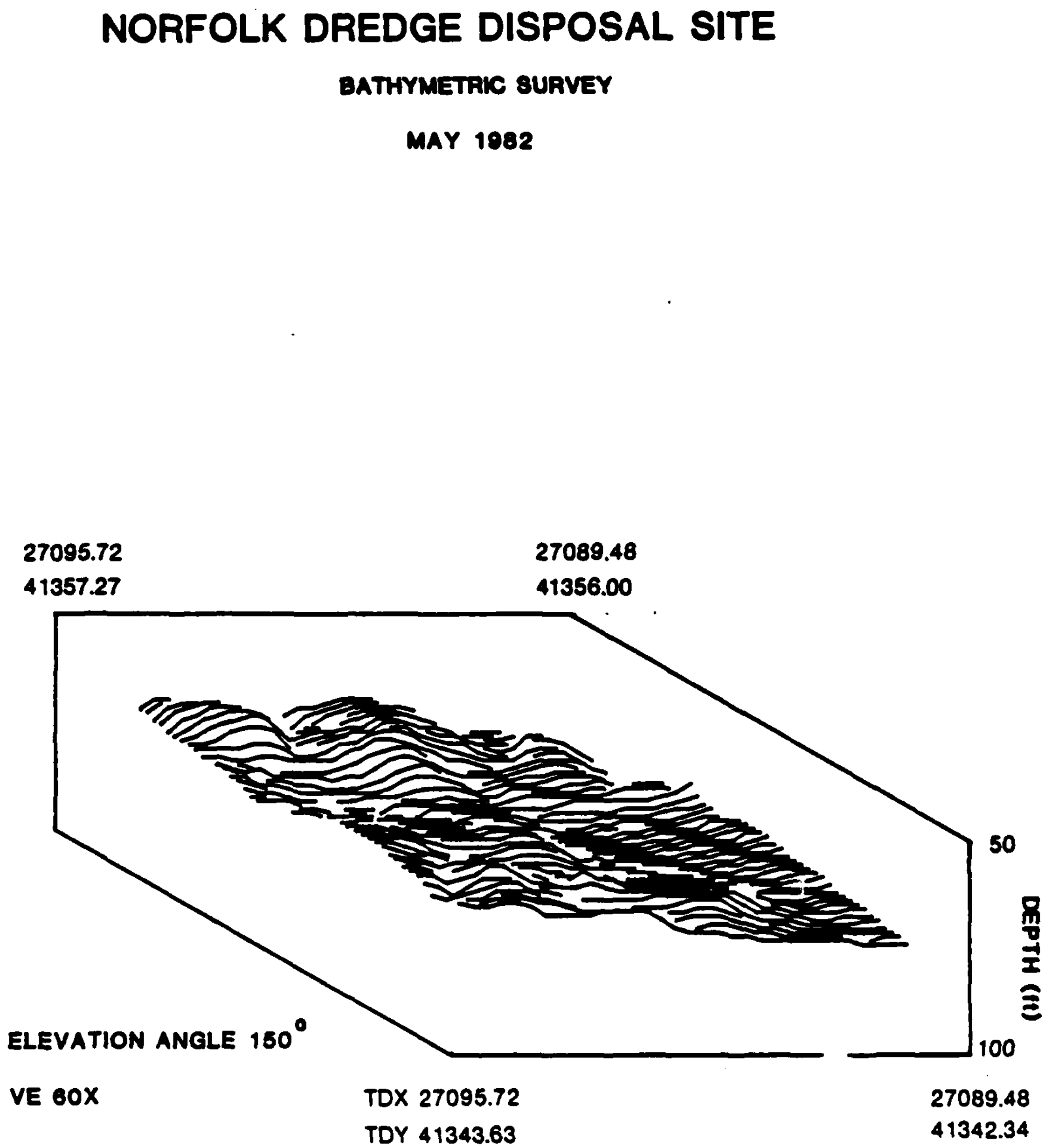

Figure 11. Bathymetric projection of study area, with a 150° projection angle. Projection based upon May 1982 data set.

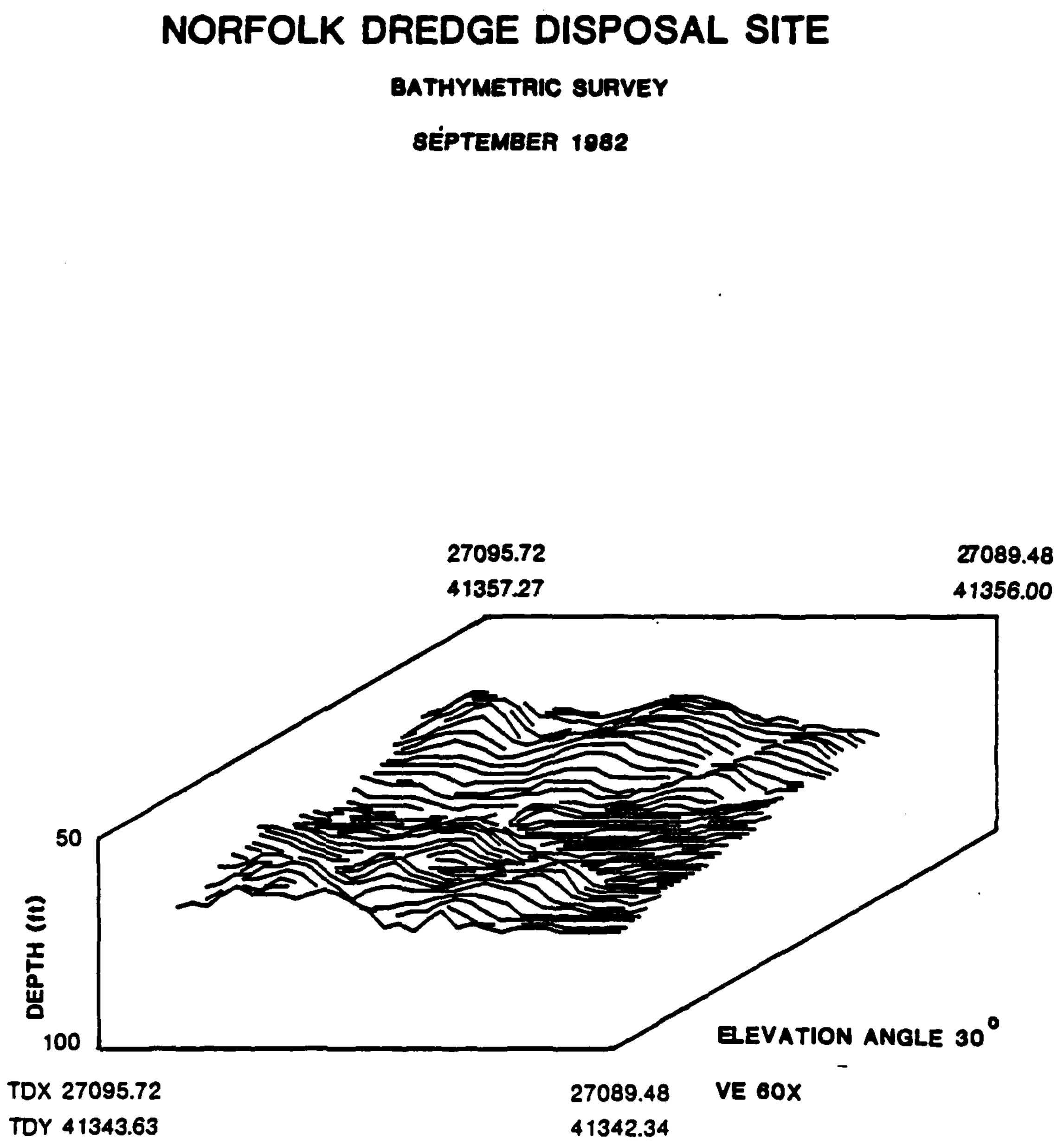

Figure 12. Bathymetric projection of study area, with a 30^0 projection angle. Projection based upon September 1982 data set.

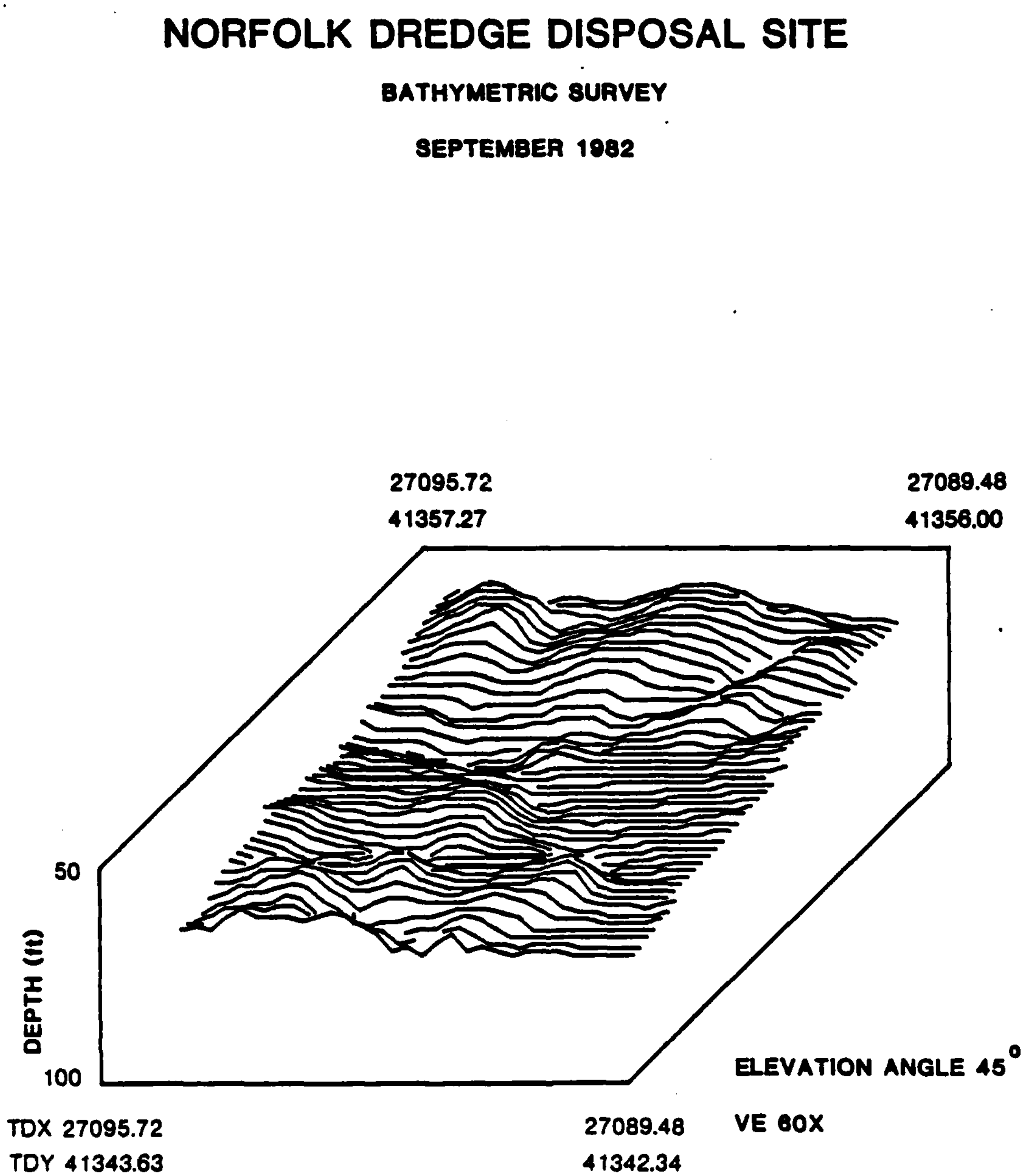

Figure 13. Bathymetric projection of study area, with a 45^0 projection angle. Projection based upon September 1982 data set.

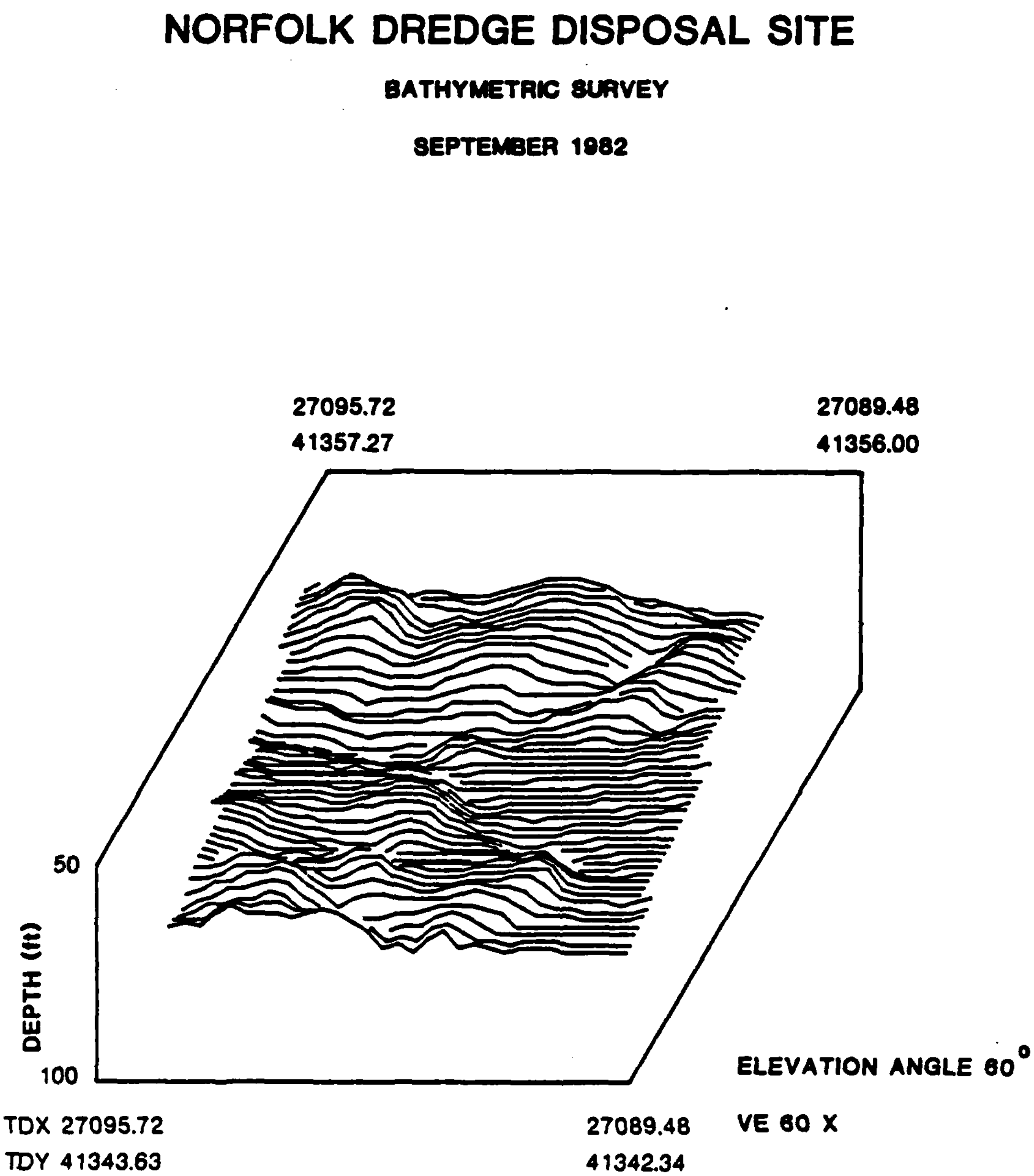

Figure 14. Bathymetric projection of study area, with a 60° projection angle. Projection based upon September 1982 data set.

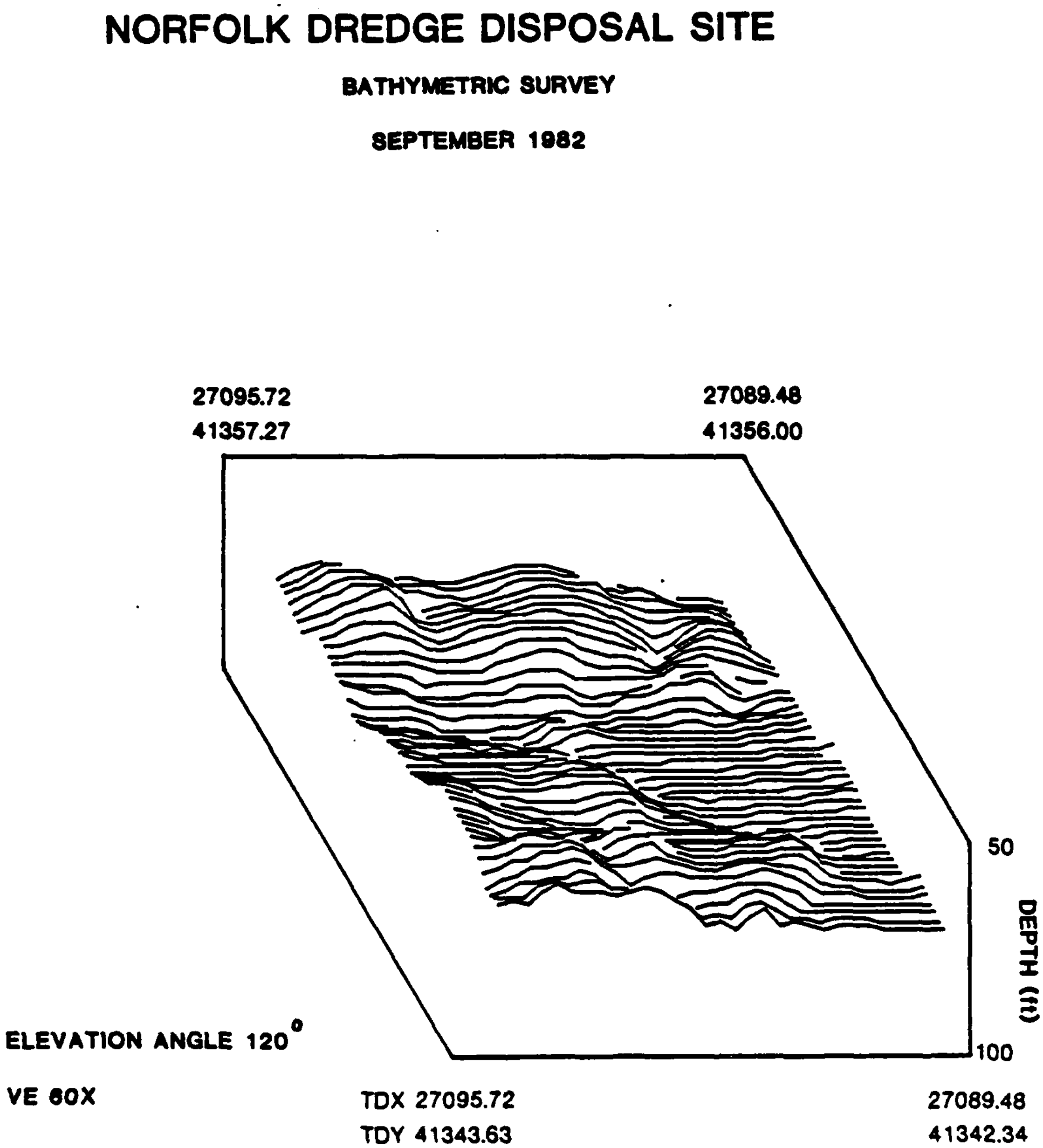

Figure 15. Bathymetric projection of study area, with a 120° projection angle. Projection based upon September 1982 data set.

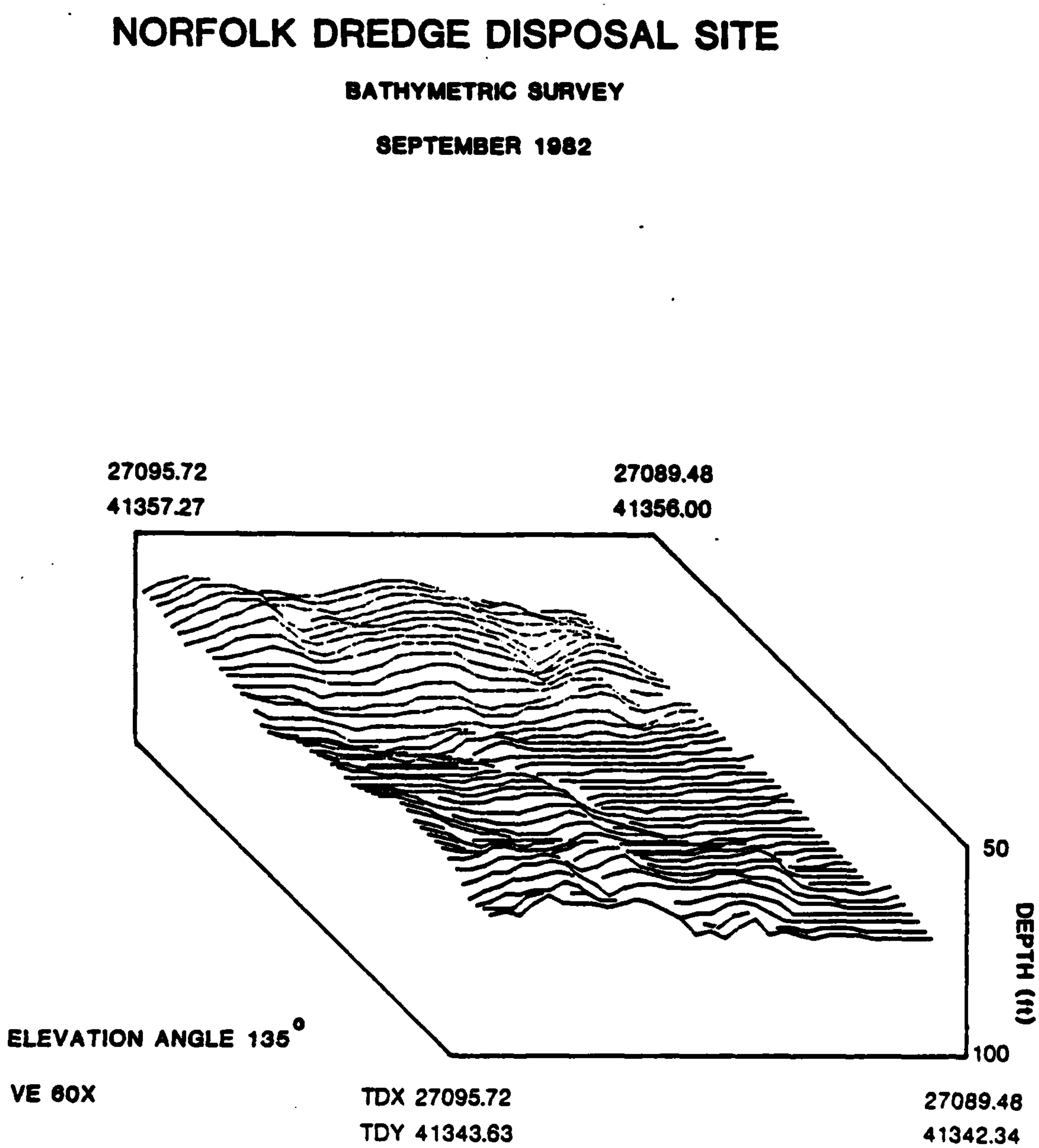

Figure 16. Bathymetric projection of study area, with a 135° projection angle. Projection based upon September 1982 data set.

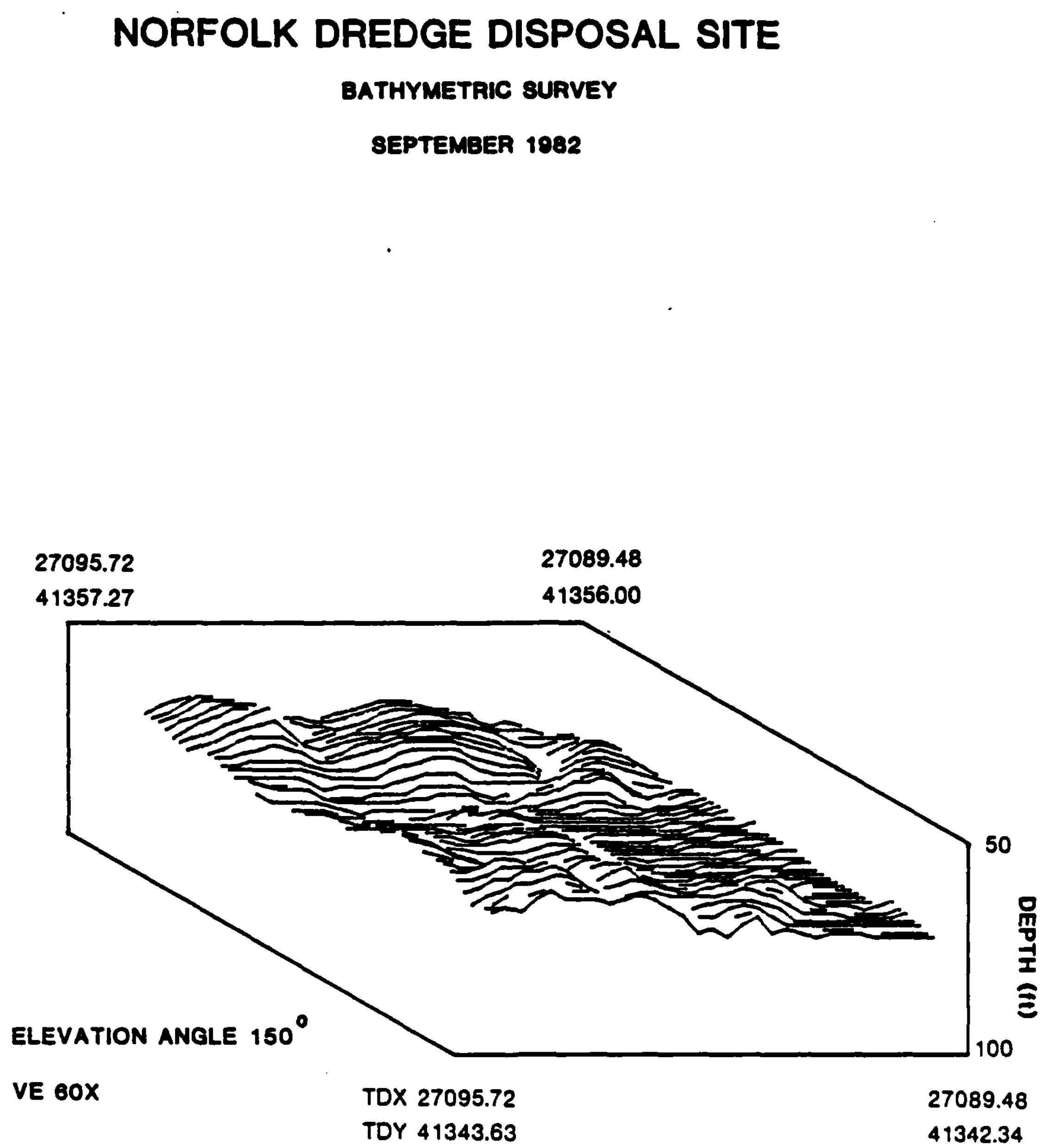

Figure 17. Bathymetric projection of study area, with a 150° projection angle. Projection based upon September 1982 data set.

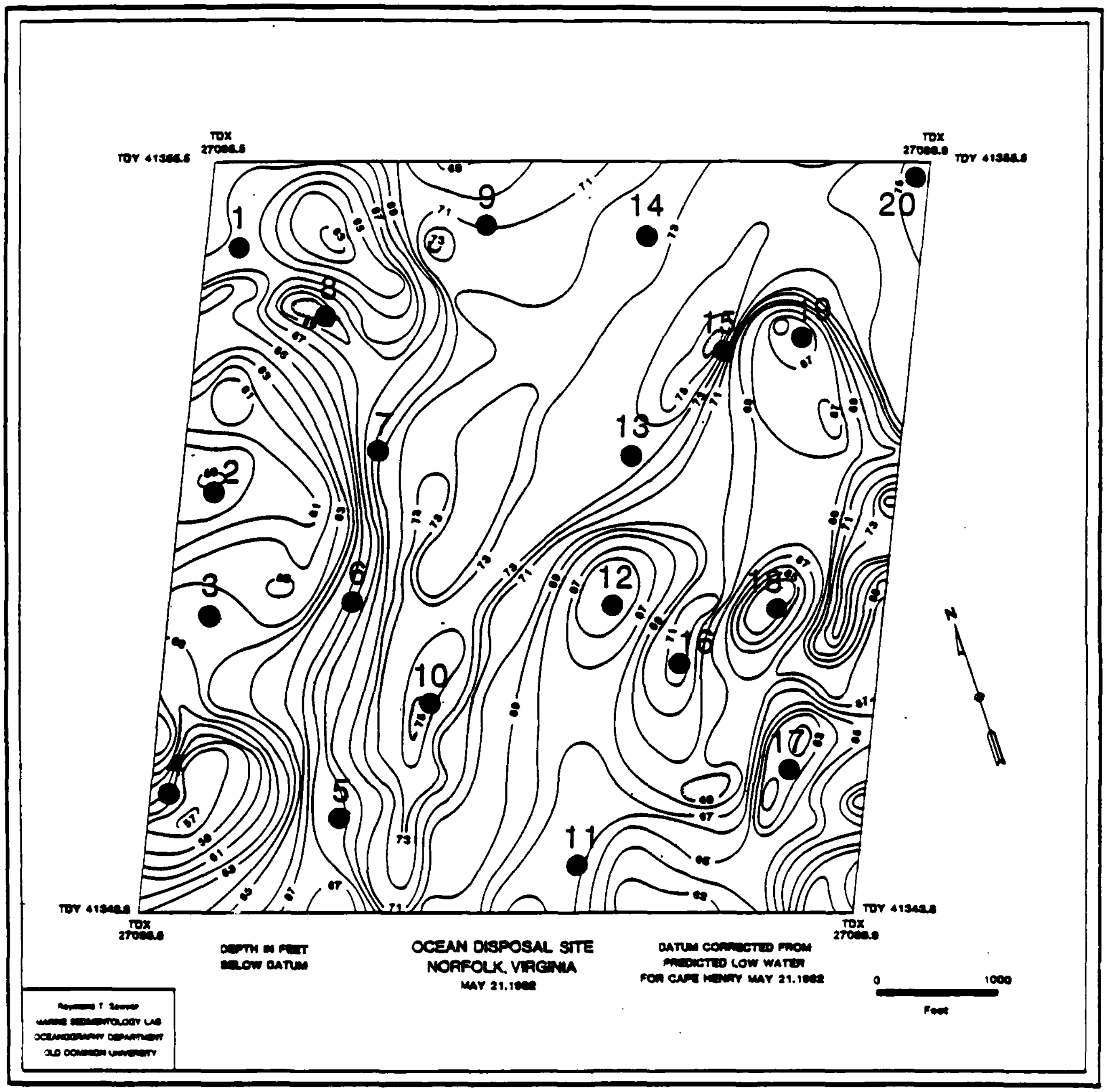

Figure 18. Location map of box core sample locations at 1 square nautical mile study area at the center of NODS (June 1982 survey).

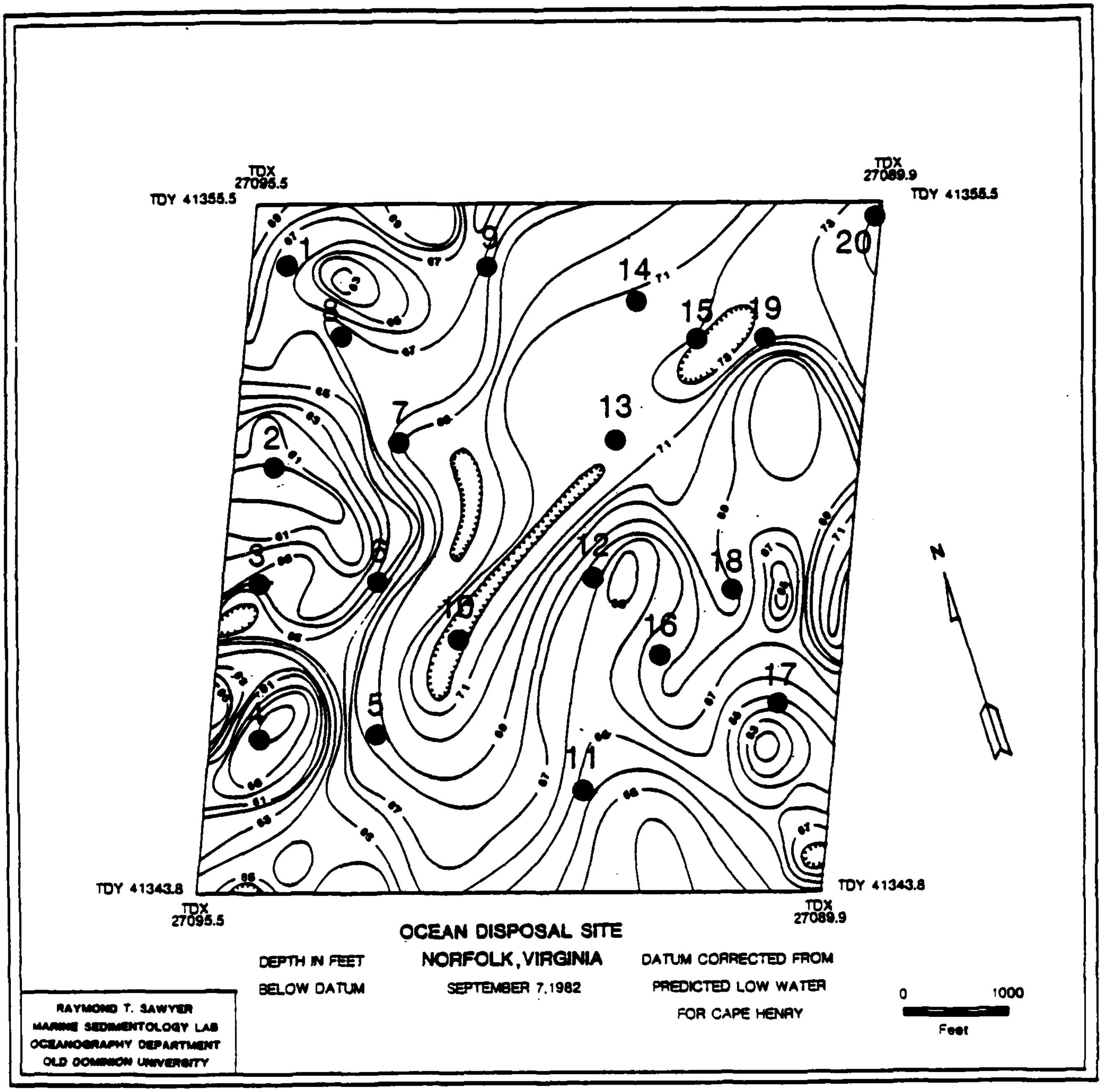

Figure 19. Location map of box core sample locations at 1 square nautical mile study area at the center of NODS (September 1982 survey).

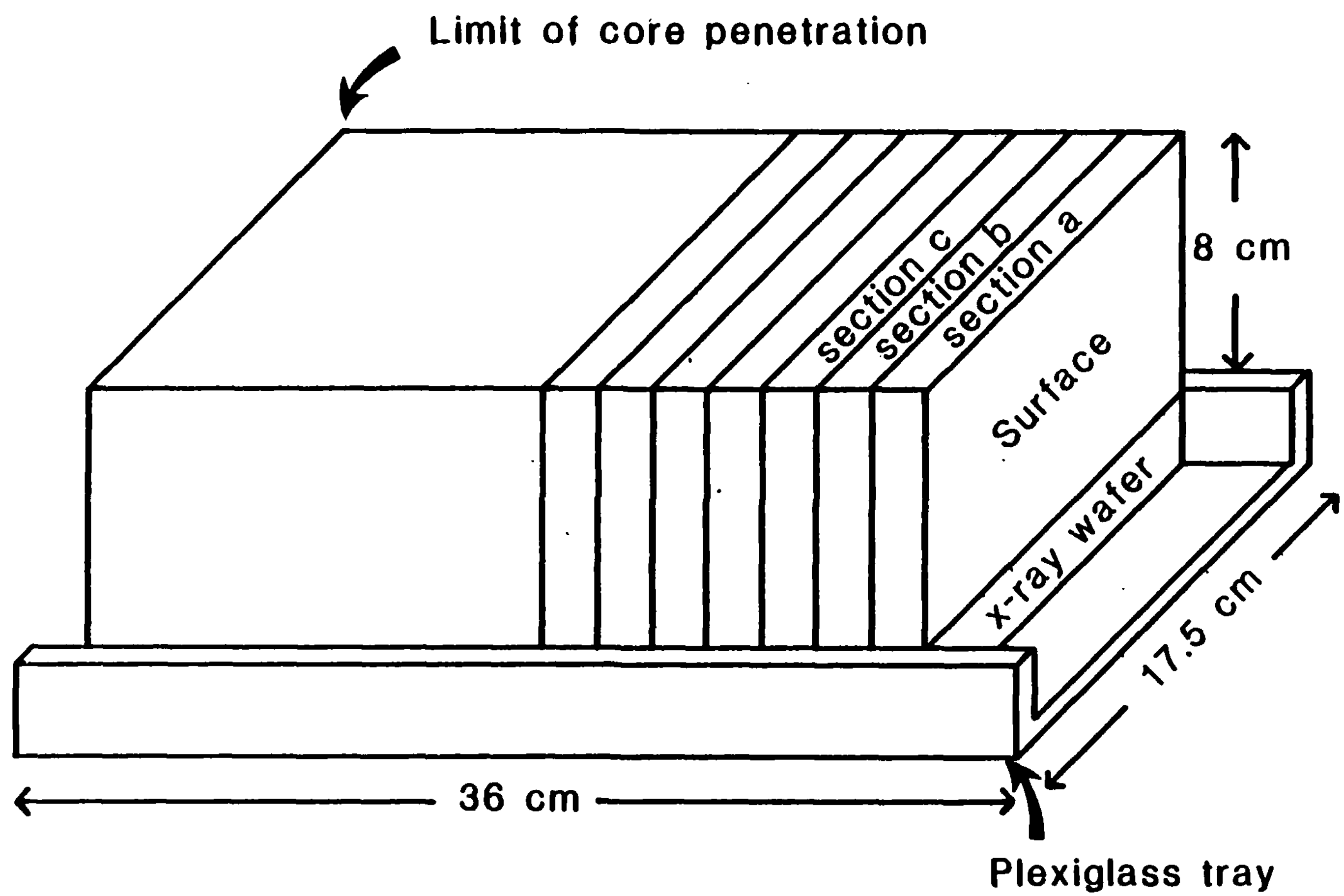

Figure 20. Diagrammatic sketch of box core sample and subsample sections for x-ray radiography and radiogeochemical analysis.

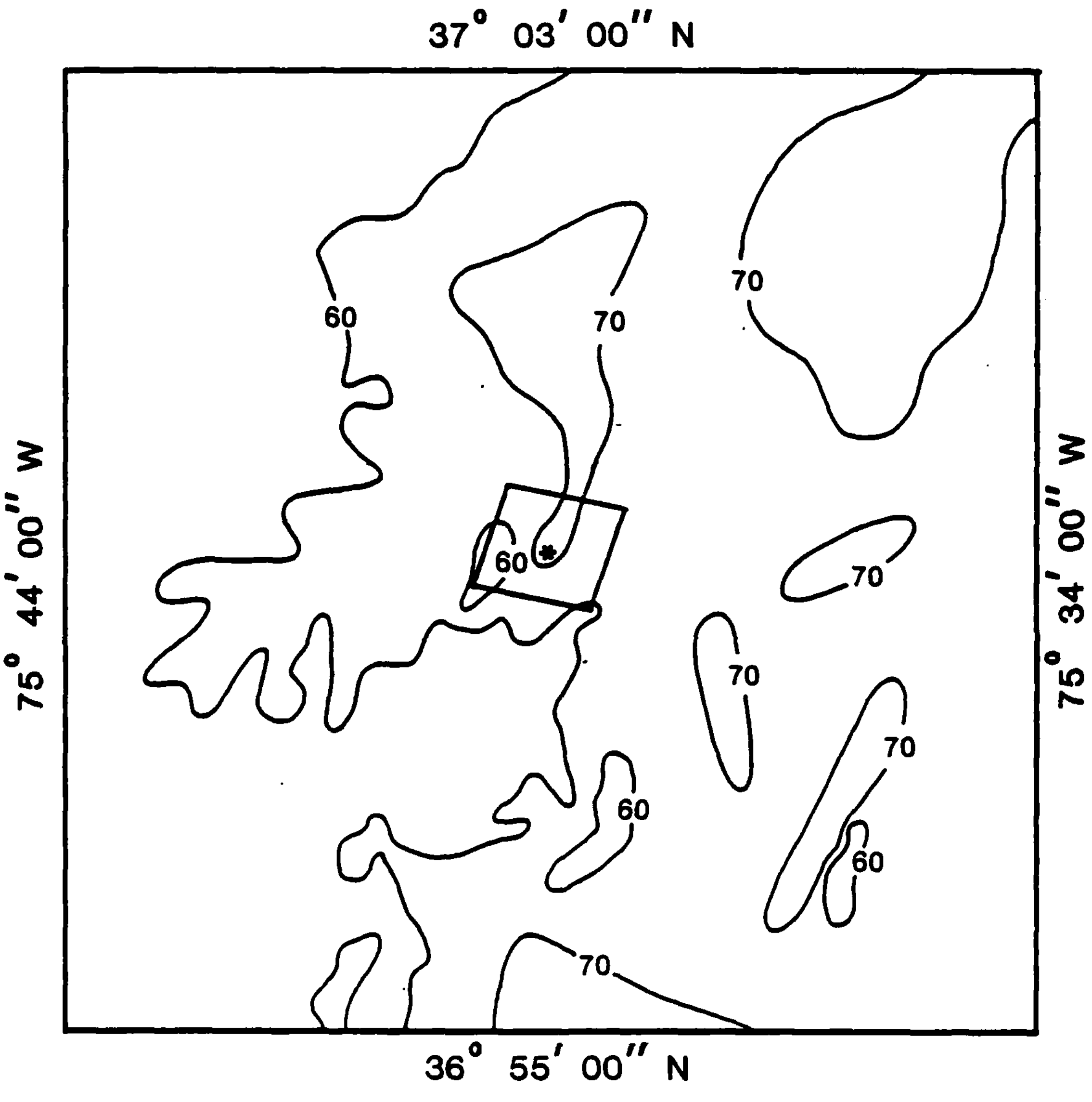

Figure 21. Chart of the Chesapeake Bay entrance illustrating the deposition of the 60 foot bathymetric contour and the morphologic configuration of a "large" potential flood channel.

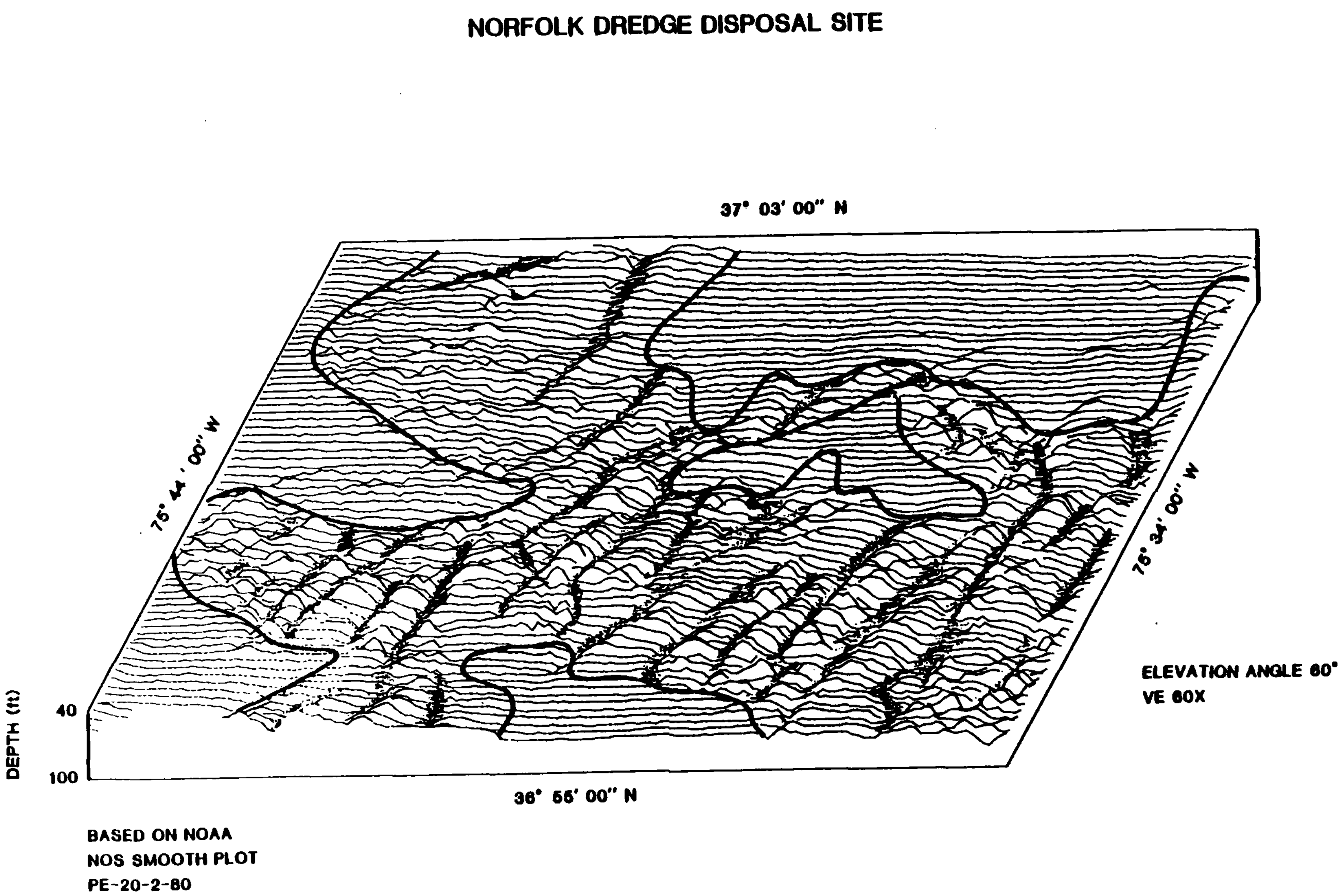

Figure 22. Bathymetric projection of 8 by 8 nautical mile area around the center of NODS illustrating ridge and swale areas, low-relief areas, and hummucky areas.

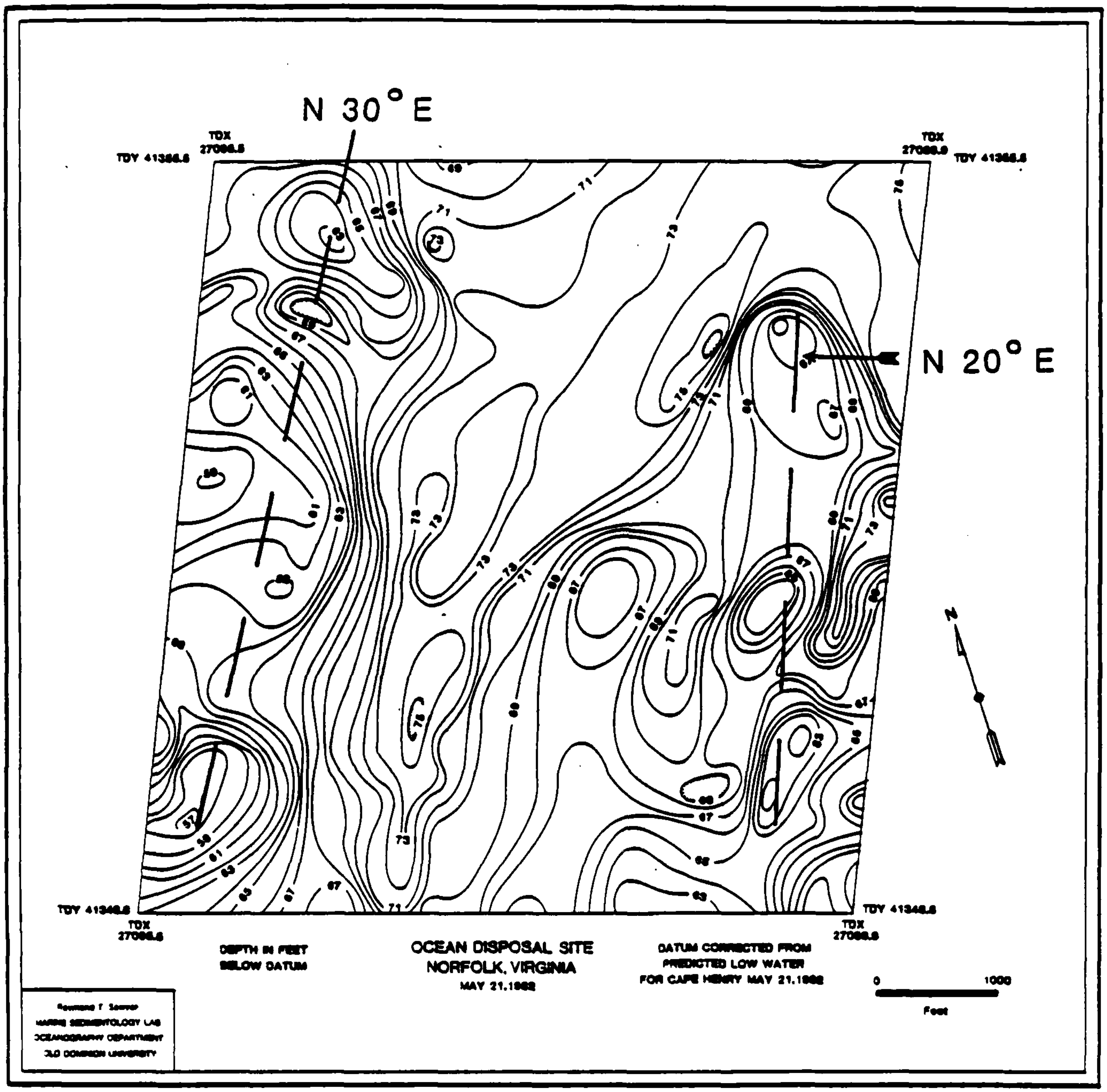

Figure 23. Bathymetric chart of study area after the May 1982 survey illustrating the approximate crests of the northeast trending ridges.

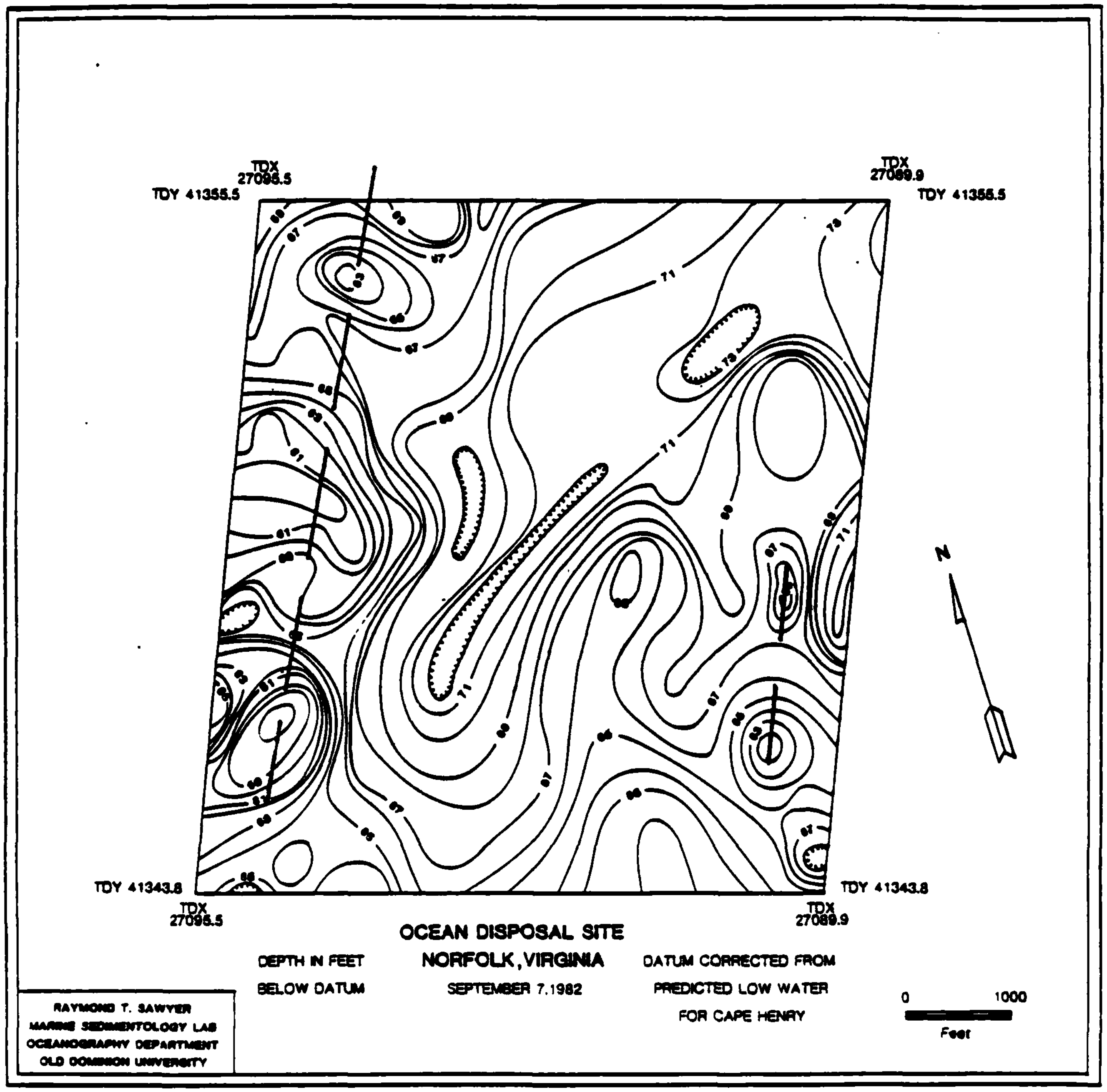

Figure 24. Bathymetric chart of, study area after the September 1982 survey.

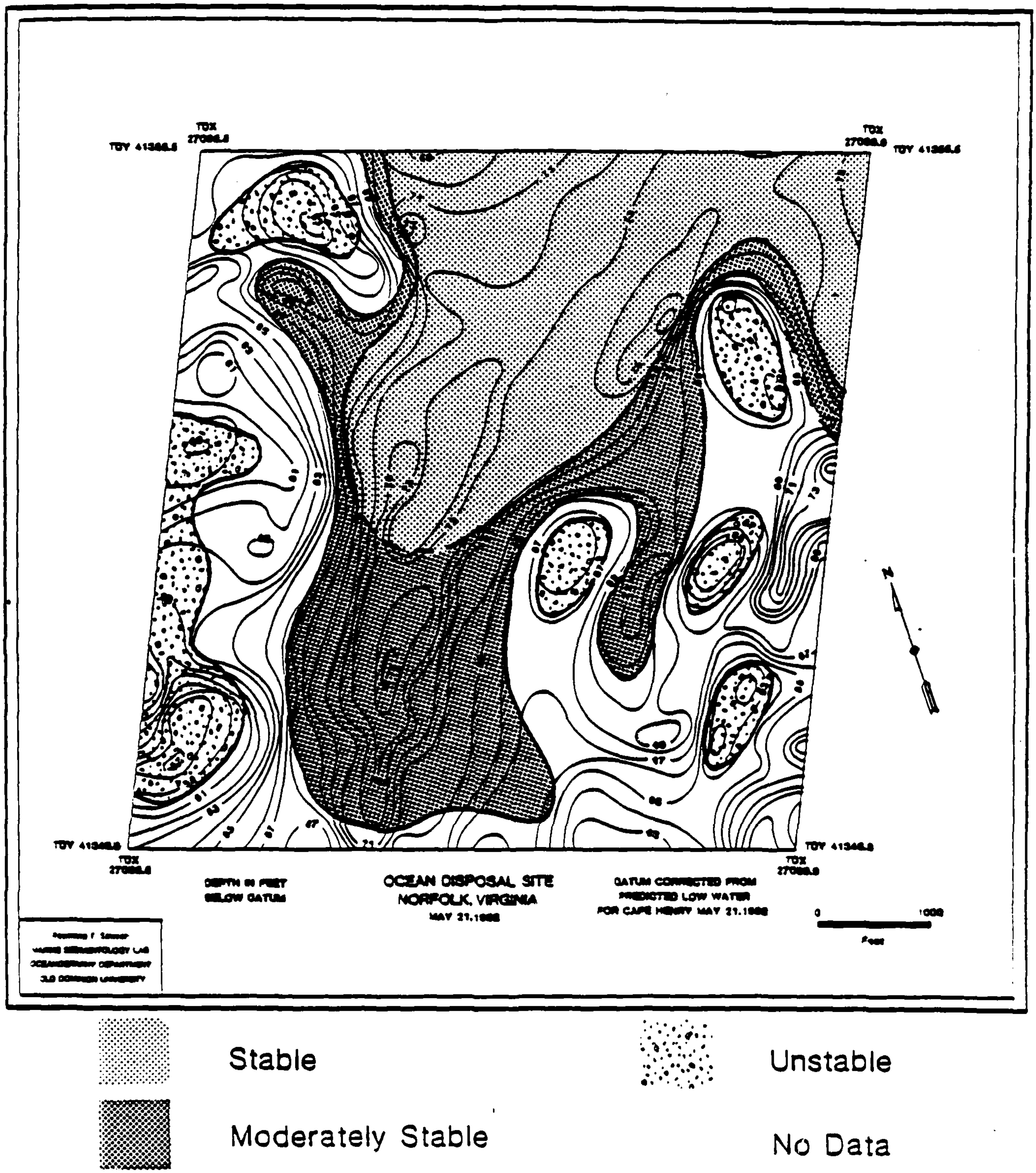

Figure 25. Bathymetric chart of study area illustrating the composite sea bed stability following the June 1982 analyses.

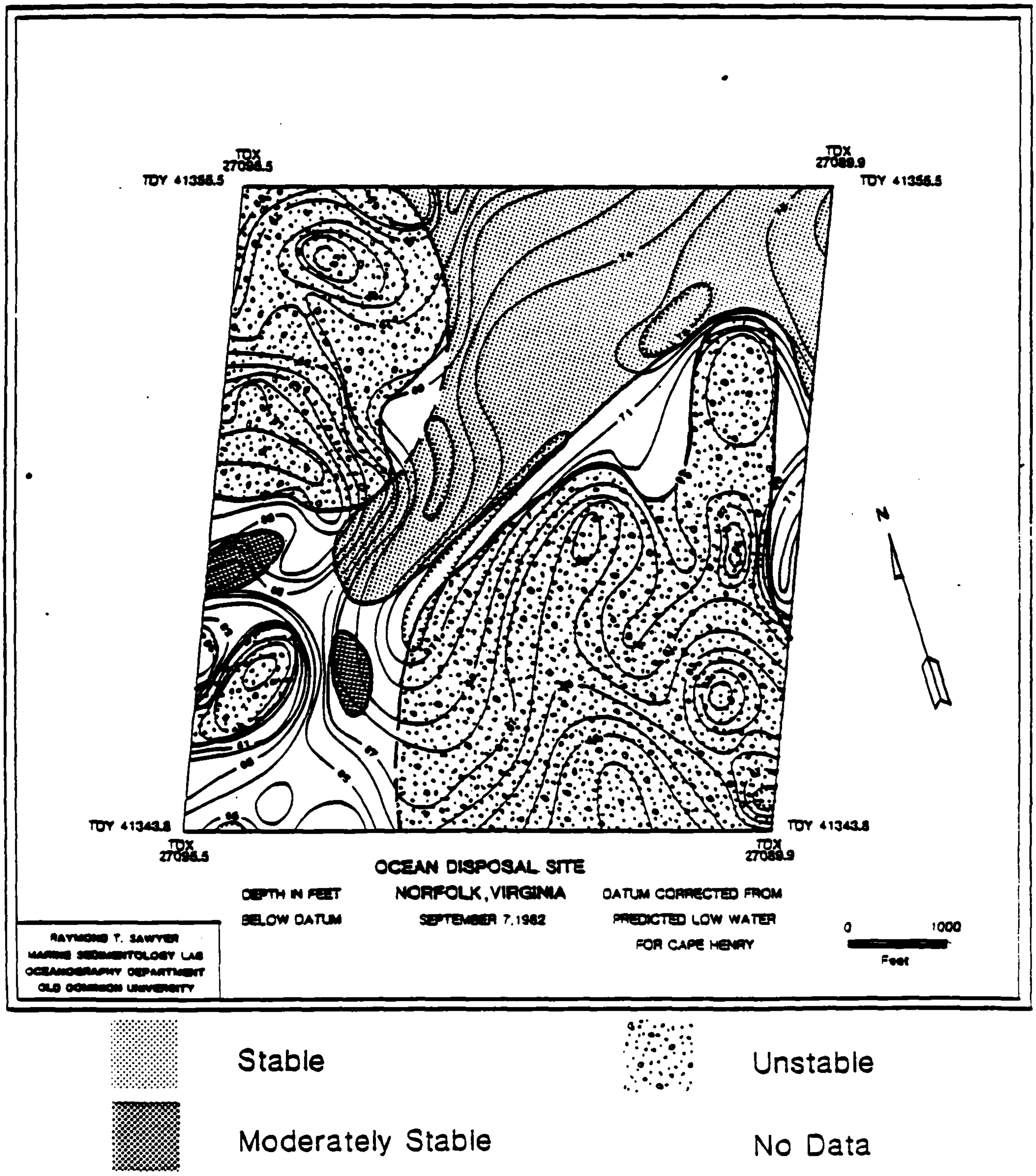

Figure 26. Bathymetric chart of study area illustrating the composite sea bed stability following the September 1982 analyses.

Appendix Ia

Thirty-five millimeter color slides of undisturbed surfaces of June 1982 box core stations.

Appendix Ib

Thirty-five millimeter color slides of undisturbed surfaces of September 1982 box core stations.

APPENDIX II
PHYSICAL AND BIOGENIC SEDIMENTARY STRUCTURES
June 23, 1982

	PHYSICAL STRUCTURES				BIOGENIC STRUCTURES					
SAMPLE NO.	RIPPLE FORESETS	INTERMED. FORESETS	HORIZONTAL LAMINAE	TABULAR TEXTURAL BEDS	MICRO-LOCOMOTION	MACRO-LOCOMOTION	BURROWS and DWELLING TUBES VERTICAL	BURROWS and DWELLING TUBES INCLINED	TUBE WIDTH	UNKNOWN
ODS-1	-	Outlined by shells 6-18 cm	-	-	-	0-10% very faint 1-4 cm	-	-	-	Shell hash 0-6 cm 18-24 cm
ODS-2	-	Faint structures 12-20.5 cm	-	-	0-20% 14-20.5 cm	60-100% large swirls 0-12 cm	-	-	-	-
ODS-3	-	In several locations 0-13 cm	-	-	30-60% 6-8 cm, 13-20 cm	-	-	-	-	-
ODS-4	-	-	Outlined by heavy mins. 0-17 cm	-	-	-	-	-	-	-
ODS-5	-	-	-	-	10-30% 0-13 cm	-	10-30% 0-10 cm	-	mostly small	randomly oriented shell hash 0-13 cm
ODS-6	Small foreset structures from 0-1 cm	-	-	-	60-100% 0-18 cm	-	10-30% 0-18 cm	-	mostly small some interm.	-

APPENDIX II(continued)
PHYSICAL AND BIOGENIC SEDIMENTARY STRUCTURES
June 23, 1982

	PHYSICAL STRUCTURES				BIOGENIC STRUCTURES					
SAMPLE NO.	RIPPLE FORESETS	INTERMED. FORESETS	HORIZONTAL LAMINAE	TABULAR TEXTURAL BEDS	MICRO-LOCOMOTION	MACRO-LOCOMOTION	BURROWS and DWELLING TUBES VERTICAL	BURROWS and DWELLING TUBES INCLINED	TUBE WIDTH	UNKNOWN
ODS-7	-	-	-	-	60-100% 0-20 cm	-	10-30% 0-10 cm	-	mostly small	-
ODS-8	Small foreset structures from 0-2 cm	-	Outlined by shells & heavy mins. 6-13 cm	-	60-100% 1-6 cm 13-16 cm	10-30% -right hand side 2-6 cm	-	-	-	-
ODS-9	-	-	-	-	60-100% 0-15 cm	-	10-30% 0-15 cm	-	mostly small	-
ODS-10	-	-	-	-	-	-	10-30% 0-11 cm	-	small to interm.	Shell hash 0-11 cm
ODS-11	-	-	-	-	-	-	-	-	-	randomly oriented shell hash 0-20 cm
ODS-12	-	-	-	-	-	-	-	-	-	shell hash 0-15 cm

APPENDIX 11 (concluded)
PHYSICAL AND BIOGENIC SEDIMENTARY STRUCTURES
June 23, 1982

SAMPLE NO.	PHYSICAL STRUCTURES: RIPPLE FORESETS	INTERMED. FORESETS	HORIZONTAL LAMINAE	TABULAR TEXTURAL BEDS	BIOGENIC STRUCTURES: MICRO-LOCOMOTION	MACRO-LOCOMOTION	BURROWS and DWELLING TUBES: VERTICAL	BURROWS and DWELLING TUBES: INCLINED	TUBE WIDTH	UNKNOWN
ODS-13	-	-	-	3 beds 0-11 cm 11-15 cm 15-20.5 cm	60-100% 0-20.5 cm	-	0-30% 0-13 cm	-	small	-
ODS-14	-	-	-	-	60-100% 0-18 cm	-	0-30% 0-8 cm	-	small	-
ODS-15	-	-	-	-	30-60% 0-21 cm	-	30-60% 0-21 cm	-	all sizes	-
ODS-16	-	-	-	-	30-60% 0-21 cm	10-30% right hand side 10-21 cm	10-30% 0-8 cm	-	mostly small	-
ODS-17	-	-	Outlined by shells 4-12 cm	-	-	-	-	-	-	Shell hash 0-4 cm 12-16.5 cm
ODS-18	-	Outlined by heavy mins. & shells 3-10 cm	-	-	60-100% 0-3 cmm 10-16.5 cm	-	-	-	-	-
ODS-19	-	-	Accented by heavy mins. 0-6 cm	-	10-30% 6-15 cm	-	-	-	-	
ODS-20	-	-	-	-	60-100% 0-18 cm	-	10-30% 0-18 cm	-	small & interm.	-

APPENDIX 111
PHYSICAL AND BIOGENIC SEDIMENTARY STRUCTURES
September 16, 1982

SAMPLE NO.	PHYSICAL STRUCTURES: RIPPLE FORESETS	PHYSICAL STRUCTURES: INTERMED. FORESETS	PHYSICAL STRUCTURES: HORIZONTAL LAMINAE	PHYSICAL STRUCTURES: TABULAR TEXTURAL BEDS	BIOGENIC STRUCTURES: MICRO-LOCOMOTION	BIOGENIC STRUCTURES: MACRO-LOCOMOTION	BIOGENIC STRUCTURES: BURROWS and DWELLING TUBES: VERTICAL	BIOGENIC STRUCTURES: BURROWS and DWELLING TUBES: INCLINED	BIOGENIC STRUCTURES: TUBE WIDTH	UNKNOWN
ODS-1	-	-	Outlined by small shells 12-24 cm	-	-	-	-	-	-	Shell hash 0-12 cm
ODS-2	-	-	Shell layer at 8 cm and 14-15 cm	-	-	-	-	-	-	Shell hash 0-8 cm 8-14 cm, 15-18.5 cm
ODS-3	-	Outlined by heavy, min., 7-9 cm, 15-17 cm	-	-		30-60% 0-7 cm, 9-15 cm	-	-	-	17-20 cm too many cracks
ODS-4	Herringbone x-bedding 0-7 cm *	Outlined by heavy, min., 7-15 cm	-	-	-	-	-	-		15-19 cm shell hash
ODS-5	-	-	12-19 cm	Shell layer 0-12 cm fine sand 12-15 cm shell 15-19cm	-	0-12 cm right hand side of core	10-30% 0-15 cm	-	interm.	-
ODS-6	-	Faint 0-1 cm	-	-	60-100% 0-15.5 cm	10-30% left hand side 0-15.5 cm	10-30% 0-15.5 cm	-	interm.	-

APPENDIX III (continued)
PHYSICAL AND BIOGENIC SEDIMENTARY STRUCTURES
September 16, 1982

SAMPLE NO.	PHYSICAL STRUCTURES RIPPLE FORESETS	INTERMED. FORESETS	HORIZONTAL LAMINAE	TABULAR TEXTURAL BEDS	BIOGENIC STRUCTURES MICRO-LOCOMOTION	MACRO-LOCOMOTION	BURROWS and DWELLING TUBES VERTICAL	INCLINED	TUBE WIDTH	UNKNOWN
ODS-7	-	Shelly 0-10 cm	Shells & med. sand 11-13 cm	-	-	-	-	-	-	Shell hash pockets 0-11 cm shell hash 13-22 cm
ODS-8	-	-	-	Alternating shell layers 0-16 cm	-	-	-	-	-	shell hash 16-20.5 cm
ODS-9	-	-	-	-	60-100% few shells & shell frags. 4-15.5 cm	-	0-10% 0-4 cm	-	small	-
ODS-10	-	-	in mud layer 21-24 cm	-	-	in mud and just above 18-24 cm	one tube 7-11 cm	-	large	shell hash 0-18 cm
ODS-11	-	Faint 7-13 cm	-	-	-	-	-	-	-	shell hash 0-18 cm
ODS-12	-	Faint 0-13 cm	-	-	-	-	-	-	-	shell hash 0-23 cm

APPENDIX III (concluded)
PHYSICAL AND BIOGENIC SEDIMENTARY STRUCTURES
September 16, 1982

	PHYSICAL STRUCTURES				BIOGENIC STRUCTURES					
SAMPLE NO.	RIPPLE FORESETS	INTERMED. FORESETS	HORIZONTAL LAMINAE	TABULAR TEXTURAL BEDS	MICRO-LOCOMOTION	MACRO-LOCOMOTION	BURROWS and DWELLING TUBES VERTICAL	BURROWS and DWELLING TUBES INCLINED	TUBE WIDTH	UNKNOWN
ODS-13	-	-	-	-	60-100% 0-15.5 cm	-	0-10% 0-10 cm	-	interm.	-
ODS-14	-	-	-	-	60-100% 0-15.5 cm	-	0-30% 0-11 cm	some 0-3 cm	small to interm.	-
ODS-15	-	-	-	-	60-100% 0.16.5 cm	-	0-30% 0-13 cm	-	small, interm., and large	-
ODS-16	-	Outlined by small shells 10-13 cm	Very pronounced -shells & grains 3-10 cm	-	-	-	0-10% faint traces 0-16 cm	-	large	mixed shell hash 0-3 cm 13-16 cm
ODS-17	-	-	-	Tabular, oriented shell bed 10-12 cm	-	30-60% well-mixed sand & shells 12-18.5 cm	-	-	-	0-10 cm shell hash
ODS-18	-	-	-	-	-	-	-	-	-	shell hash 0-13 cm
ODS-19	-	Outlined by heavy mins. 4-8 cm	Outlined by heavy mins. 0-10 cm	-	60-100% 10-13 cm	-	-	-	-	-
ODS-20	-	-	-	-	60-100% 0-16 cm	-	0-30% 0-12 cm	-	small and interm.	-

APPENDIX IV. Diver Disposition Form for Magnetometer "Truthing"

DISPOSITION FORM

For use of this form, see AR 340-15; the proponent agency is TAGO.

REFERENCE OR OFFICE SYMBOL	SUBJECT
NAOPL-R	Norfolk Harbor Channels Deepening Cultural Resources Survey

TO	FROM	DATE	CMT 1
THRU: Ch, Planning Div	Ch, Env Anlys Br	23 Aug 82 MELCHOR/dh	

TO: Planning Division Files

1. After extensive coordination with VRCA and Wilmington District, a magnetometer survey of previously undredged areas in Norfolk Harbor deepening project area was conducted on Wilmington's survey boat "Beaufort" between 12-26 May 1982.

2. Individuals involved in project:

VRCA	Wilmington Dist.	Norfolk Dist.
John Broadwater	Glenn Boone	Helene Haluska
	Bernie Davis	Jim Melchor
	Barry Guthrie	
	Richard Kimmel	
	Craig Schillinger	
	Howard Varnam	

3. On 27 July 1982, Kimmel, Broadwater, Haluska, and Melchor met in Norfolk District office to discuss findings of magnetometer survey and to select targets which needed additional investigation. Thirteen targets were selected; however, two were subsequently eliminated as they were determined to be in naturally deep water greater than proposed dredging depths.

4. Between 16-20 Aug 82, "Beaufort" returned to Norfolk and dives and/or hydrographic reconnaissance surveys were conducted at the 11 target sites.

5. Individuals involved in project:

VRCA	Divers	Norfolk Dist.	Wilmington Dist.
John Broadwater	Bonnie Brown (ODU)	Helene Haluska	Glenn Boone
	Charlie Farmer (ODU)	Jim Melchor	Bernie Davis
	Ray Sawyer (ODU)		Barry Guthrie
	Keith Christian (British Army)		Howard Varnam
	Tony Stamford (British Army)		
	Malcolm Strickland (British Army)		

6. Target locations and findings:

#1 Hampton Roads X2635378.24 Y243418.38, piece of steel sheet metal less than 2 feet square approximately 1/8" thick, depth 48 feet (slack low).

#2 Hampton Roads X2635637.58 Y243653.43, piece of steel cable approximately 1-1/4" thick roughly 12 feet long, depth 51 feet (slack low).

APPENDIX IV. (Concluded)

NAOPL-R 23 August 1982
SUBJECT: Norfolk Harbor Channels Deepening Cultural Resources Survey

#3 Thimble Shoal Channel (w. end) X2655111.13 Y254157.76, water depth near low tide exceeded 60 feet, dredging not required, no dive, no indications on hydro survey.

#4 Thimble Shoal Channel (w. end) X2656073.24 Y253884.92, water depth near low tide exceeded 70 feet, dredging not required, no dive, no indications on hydro survey.

#5 Thimble Shoal Channel (e. end) X2723801.0 Y233846.0, iron hull wreck of steam harbor tender or "examination vessel" (NOAA description), roughly 20 feet long, water depth 65 feet at slack high, top of wreck approximately 56 feet deep.

#6 Atlantic Ocean Channel X2765523.09 Y210006.78, no finds.

#7 Atlantic Ocean Channel X2769734.80 Y208150.97, no finds.

#8 Atlantic Ocean Channel X2774591.81 Y203371.52, small spool of stainless steel wire approximately 6" diameter X 3" thick.

#9 Atlantic Ocean Channel X2774310.51 Y200905.07, no finds but near plotted wreck near CB buoy, NOAA description - "large round metal casing probably remains of navigation buoy".

#10 Atlantic Ocean Channel X2778876.18 Y198082.46, no finds.

#11 Atlantic Ocean Channel X2781826.83 Y195532.23, 10-12 Navy (WWII) "Hedgehogs" (antisub weapons) scattered over roughly 50 feet, one recovered and given to EOD Unit, water depth 54 feet near low tide.

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